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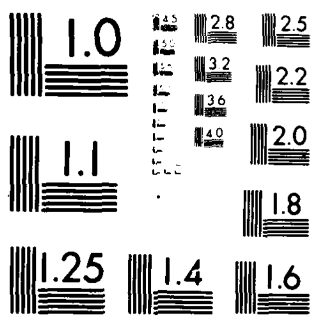

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DARK ADAPTATION OF RATED AIR FORCE
OFFICERS USING ELECTROLUMINESCENT
VERSUS INCANDESCENT LIGHT SOURCES

George K. Blouin, Captain, USAF

LSSR 56-81

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An experimental study was conducted to determine the effects of electroluminescent versus incandescent light sources on the dark adaptation of rated Air Force officers. The parameters of dark adaptation that were tested are (1) absolute luminance threshold of vision; (2) resolution of visual detail as provided by square wave spatial frequency gratings; and (3) comfort level of cockpit lighting as determined by rated Air Force personnel. Results show that (1) electroluminescent and incandescent light sources have the same effect on the absolute luminance threshold and the resolution of visual detail; and (2) significant differences exist between the two light sources in the comfort level of cockpit lighting as chosen by the subjects.

LSSR 56-81

DARK ADAPTATION OF RATED AIR FORCE OFFICERS USING ELECTROLUMINESCENT VERSUS INCANDESCENT LIGHT SOURCES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

George K. Blouin, BSEE
Captain, USAF

September 1981

This thesis, written by

Captain George K. Blouin

has been accepted by the undersigned on behalf of the Faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

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David R. Lee

COMMITTEE CHAIRMAN

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Last, but in no way least, my sincerest gratitude goes to my wife Kathy and to my children for their patience and understanding during these past 15 months.

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CHAPTER I

INTRODUCTION

Dark adaptation is defined as the increase in a person's visual sensitivity that takes place in darkness following exposure to a preadapting light. The least perceptible luminance that can just be seen, called threshold luminance, is usually what is measured (2:1). Dark adaptation of the human eye has long been of concern to the Armed Forces. The U.S. Army in 1944 commissioned a study to

> . . . determine the most efficient means whereby commanders of Field Artillery units in the field may classify their personnel according to their relative abilities to see at night . . . [1:1].

Studies of dark adaptation continue today by all branches of the Armed Forces for such specific applications as night formation flying, submarine blackout conditions, and night map reading.

One of the many factors which affects the dark adaptation of the human eye is the type of light being used. A number of studies (Hartline et al., 1944; Webster and Lee, 1942) support the hypothesis that red light has less of an effect on the dark adaptation of the human eye than other light colors. Recent developments and improvements in electroluminescent lighting (EL) have added yet

another type of light source whose effect on dark adaptation has not been determined. Electroluminescent lighting differs from an incandescent light in that it is a solid state device which absorbs electrical energy and converts it to a steady uniform glow.

Typically, an EL lamp is a polycrystalline copper doped, zinc sulfide powder phosphor that, when excited by an alternating current, causes an electron shift within the phosphor atom, thereby releasing photons, or light. The EL lamp emits light in a relatively narrow bandwidth, has no infrared component, is capacitive in nature, and differs from the conventional incandescent light source in the same sense that transistors differ from vacuum tubes (6). It is not a new light source; but due to recent improvements in color stability, more efficient power supplies, and microencapsulation techniques, it shows great promise for a wide range of applications. The EL lamp is currently being used in buses, trucks, automobiles, and in aircraft for instrument and cargo area lighting (6). It could also be used for home security, emergency exit signs, and appliances.

Currently, the PRAM (Producibility, Reliability, Availability, Maintainability) Program Office of the Aeronautical Systems Division at Wright-Patterson AFB, Ohio, in response to Military Airlift Command Statement of Need

(MAC SON) 02-79, is conducting field experiments to determine if EL lighting is suitable for austere airfield lighting. In addition, the capabilities of EL lights on C-130 cargo and cockpit areas are being pursued by PRAM. During the tests of electroluminescent lighting on C-130 aircraft, it was stated that EL lamps "could be viewed at very close ranges without affecting night vision [5]."

Night Vision

Night vision, the ability of an individual to see at night, depends on the individual's level of dark adaptation. Dark adaptation and night vision involve increased visual sensitivity resulting from exposure to decreasing quantities of visible light. The most frequently tested aspect of dark adaptation is the absolute light level or the threshold of seeing (3:9).

> The absolute light sense is the most fundamental and most frequently measured parameter of dark adaptation. Historically, the absolute, minimal, contrast, or relative brightness thresholds have been used as the criteria of individual night vision ability [3:36].

Visual acuity is another factor which has an effect on night vision. Visual acuity is not only concerned with the ability of an individual to recognize a target, but also involves the capacity to discriminate fine details in an object or scene that is viewed (3:26). The discrimination of fine details or resolution involves the individual

responding to a separation between elements of a pattern. The most common pattern used is a grating pattern, similar to Figure 1, in which the widths of the dark and bright lines are made equal (4:325). Normally, a series of gratings from coarse to fine is presented and visual acuity is specified in terms of the angular width of one line for the finest grating that can be resolved (4:325).

> Visual acuity, in the sense of resolution, is the reciprocal of the angular separation between two elements of the test pattern when the two images are barely resolved [4:325].

Therefore, fine lines indicate a high degree of acuity and wide lines, a low degree.

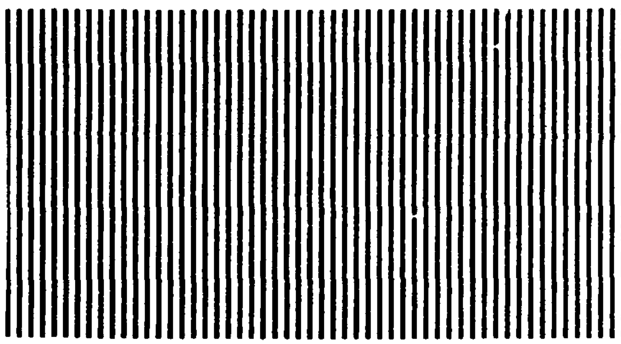


Figure 1. Acuity Grating

Dark adaptation and visual acuity may be quantified to determine an individual's night vision and the type of light source to be used, i.e., electroluminescent or incandescent may be chosen based on that quantitative data. However, once the type of light is fixed, the aircraft crewmember only has one variable which he may control and that is the qualitative variable of light comfort level.

Therefore, to test the effects of electroluminescent versus incandescent light sources on dark adaptation, this paper will focus on the quantitative aspects of absolute luminance and visual acuity as well as the qualitative aspect of light comfort level.

Problem Statement

A requirement exists for an evaluation of electroluminescent lamps to provide quantitative data of their effect on dark adaptation of the human eye. This evaluation focuses on the following:

1. Absolute Luminance Threshold of Vision
2. Resolution of Visual Detail as Provided by Square Wave Spatial Frequency Gratings (see Appendix A)
3. Comfort Level of Cockpit Lighting as Determined by Rated Air Force Personnel

Justification

By initiating a field study into the use of EL lamps in response to MAC SON 02-79, PRAM established the correlative need to evaluate EL lighting to determine:

1. The Effect of EL Lights on Human Visual Parameters
2. The Desirability of Expanding the Use of EL lighting for Cockpit and Runway Light Uses

Specifically, prior to committing additional funds and physical resources to the procurement of EL lamps for cockpit and airfield lighting, Air Force decision makers must

be provided with quantitative as well as qualitative data on electroluminescent lighting.

Objectives

To determine the effects of an EL light source on the dark adaptation threshold of the human eye.

To determine the effects of an EL light source on visual acuity using square wave spatial frequency gratings.

To determine the cockpit lighting comfort range using EL and incandescent (INC) light sources.

Hypotheses

An EL light source affects the dark adaptation threshold of the human eye in the same manner as an incandescent light source.

An EL light source affects the grating resolution, at a predetermined spatial frequency, in the same manner as an incandescent light source.

Rated Air Force personnel select the same or greater cockpit luminance levels when using an EL light source than when using an incandescent light source.

Literature Review

A large number of scientists and medical personnel have examined the endogenous factors (those factors which have an individual physiological and anatomical basis) which influence dark adaptation. Many scientists have also

examined the numerous exogenous factors (those factors which are in the environment and subject to experimental control) which influence dark adaptation. But, there is currently no research being conducted into the exogenous factor of the effect of electroluminescent lighting on the parameters of dark adaptation and visual acuity.

A literature search was conducted into the area of dark adaptation and visual acuity using electroluminescent lighting. The search included the resources of the Defense Technical Information Center (DTIC), of the Defense Logistics Agency at Alexandria, Virginia, the Integrated Visual Image Technology Section (IVITS) of the Air Force Aerospace Medical Research Laboratory (AFAMRL) at Wright-Patterson Air Force Base (WPAFB), and the Air Force Wright Aeronautical Laboratories (AFWAL) Technical Library at WPAFB.

The IVITS library is a working library specifically geared toward vision and display technology. The AFWAL library search included an index of all conference papers for the years 1973 through 1980 as provided by the Dialog Information Retrieval Service. In addition, the AFWAL search included all research in progress or completed in the past two years as listed with the Smithsonian Science Information Exchange (SSIE).

CHAPTER II

METHODOLOGY

The purpose of this chapter is to describe the apparatus used in the experiment, the scope of the experiment, and the procedures followed during the experiment.

Apparatus

Figure 2 is a schematic representation of the night vision tester (NVT) used during the experiment to provide the dark adaptation curves and the spatial threshold curves. Figure 3 is a picture of the night vision tester and the Pritchard photometer. The NVT allows for an 8 degree field of view, and the slide wheel contained five slides of varying square wave gratings. The five spatial frequencies tested with the slides were 1, 1.6, 6.25, 10, and 12.5 cycles per degree (cpd). The light source was an electroluminescent panel approximately 2 inches x 8 inches. The EL panel was filtered with the use of an ND2 filter to reduce the light output to threshold levels. The Variac controlled the voltage level to the EL panel, thereby controlling the light output. A Pritchard photometer was used to generate a calibration curve of the NVT which related the Variac voltage to a luminance level.

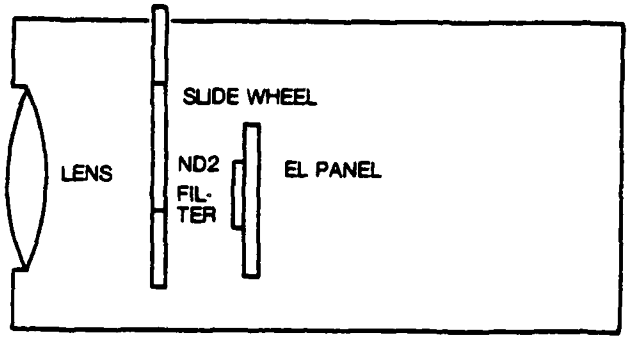


Figure 2. Schematic of the Night Vision Tester

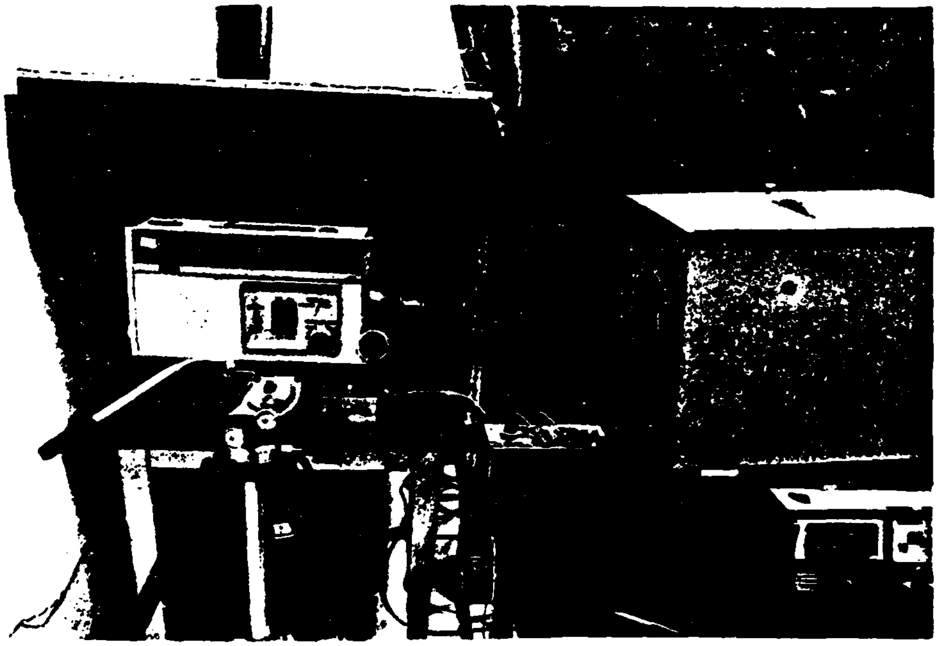


Figure 3. Night Vision Tester

The pseudo-cockpit environment, as shown in Figure 4, had four control panels or dials taken from a variety of aircraft. The panels were illuminated by either EL or incandescent lamps which were filtered to remove any color differences. Figure 5 is a graph of the relative output versus wavelength of the EL and INC light sources. Figure 6 shows where each light source falls on the Uniform Chromaticity Scale (UCS). A Variac, identical to the one on the NVT, was used to vary the voltage and subsequently the illumination of the control panels. Again, a Pritchard photometer was used for calibration curves for each light source.

The raw data was recorded by a Texas Instruments Silent 700 ASR Electronic Data Terminal, shown in Figure 7. The terminal and its associated software recorded the subject's response time as well as the voltage level for both the NVT and pseudo-cockpit area. In addition, a control box with switches to turn each Variac on or off and a switch for light source selection was provided.

Scope

The experiment was conducted using ten active duty Air Force officers. Each subject had 20/20 visual acuity with or without corrective lenses as measured with a standard eye chart. The sample was not entirely random, as the subjects were volunteers attending the Air Force Institute

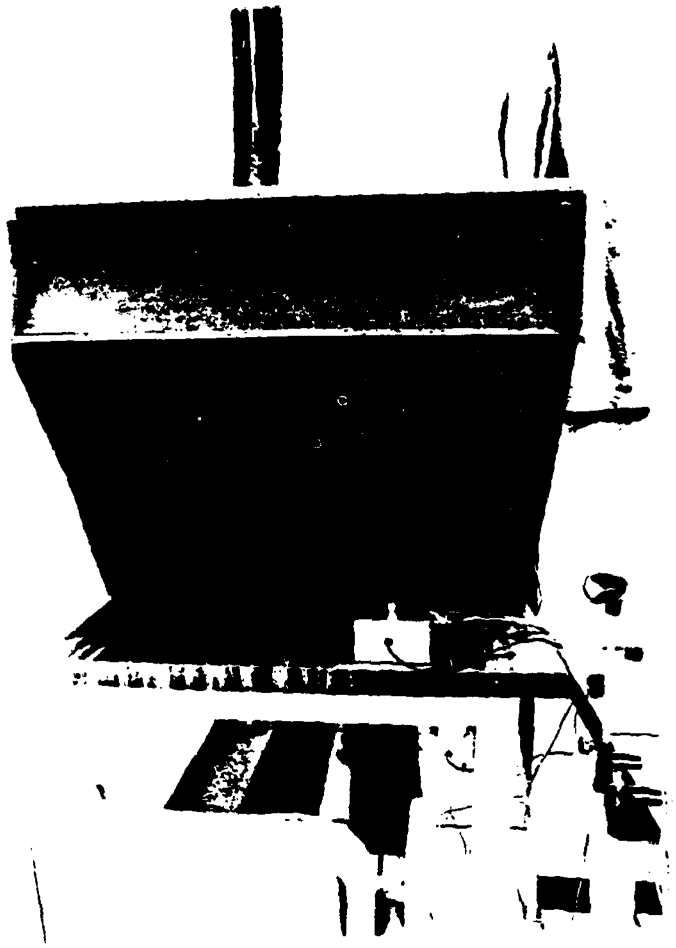


Figure 4. Pseudo-Cockpit Environment

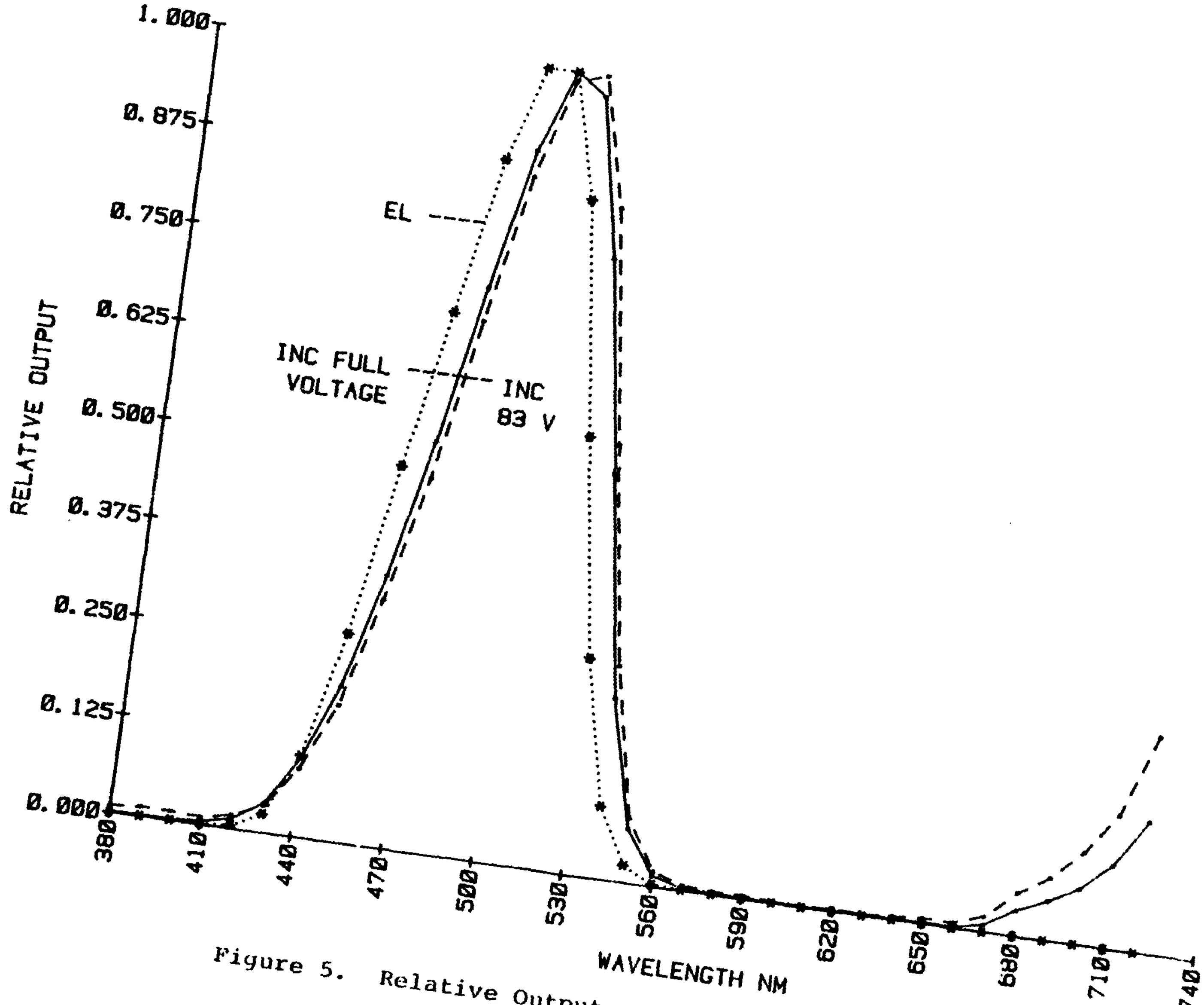


Figure 5. Relative Output versus Wavelength

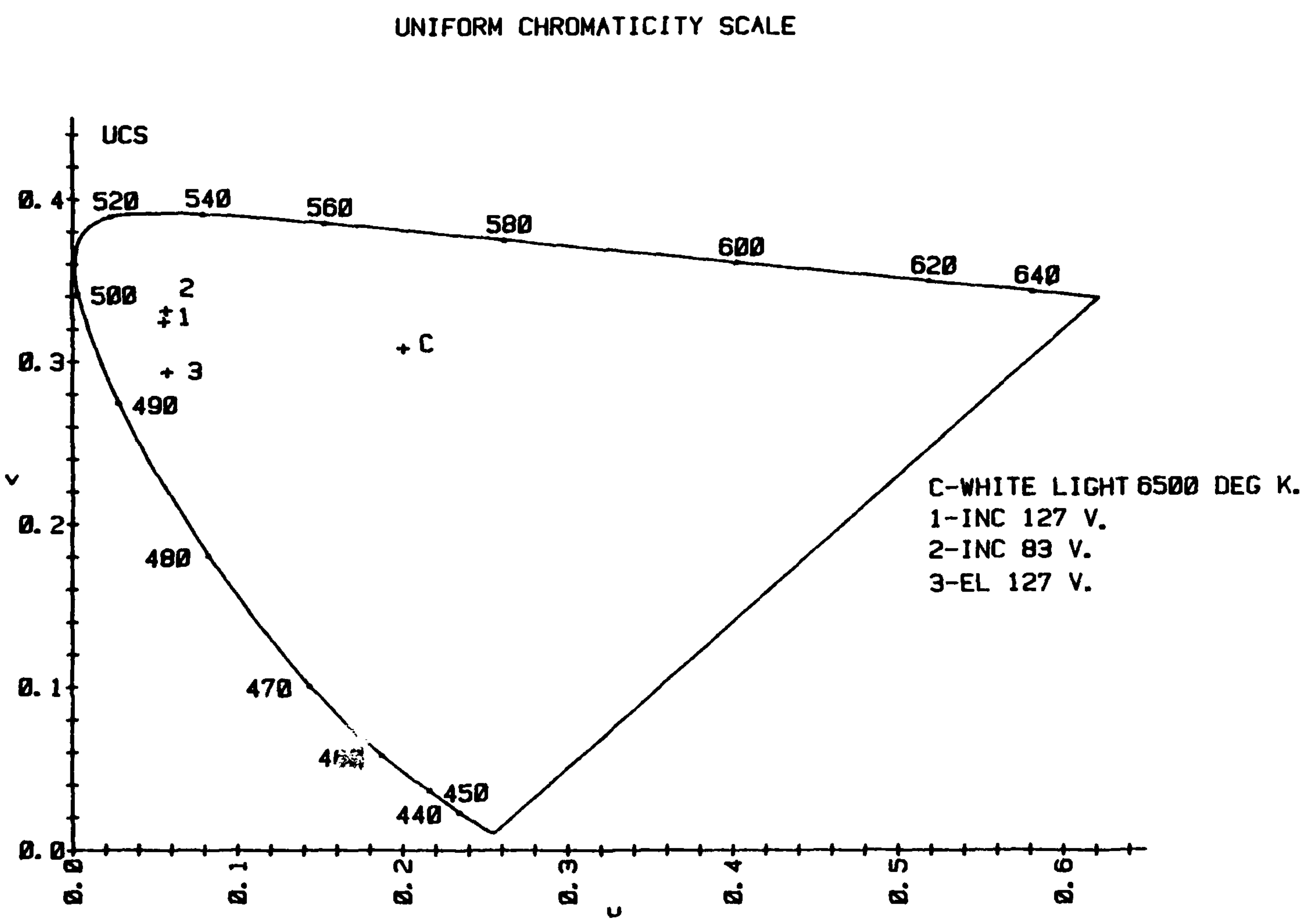


Figure 6. Uniform Chromaticity Scale

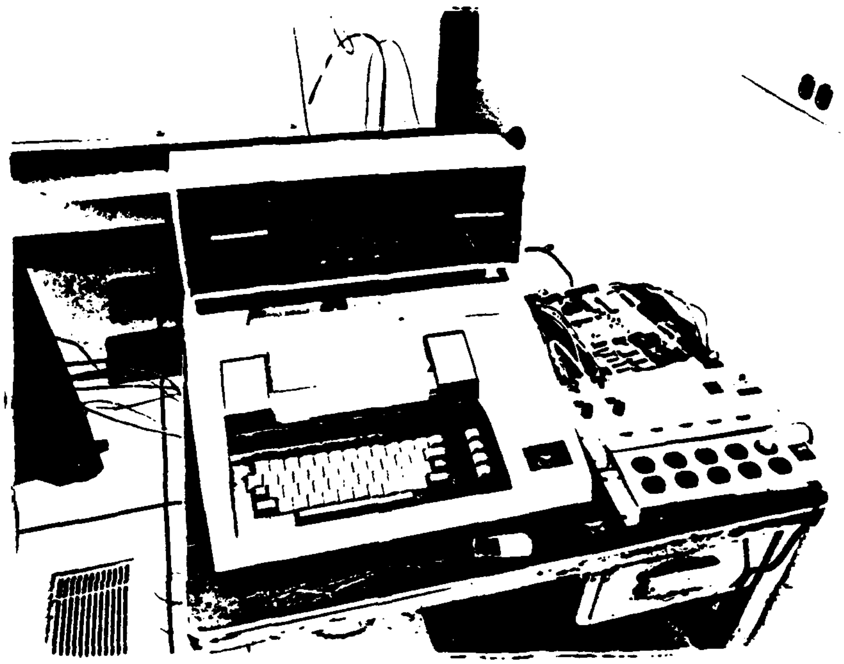


Figure 7. Texas Instrument Silent 700 Terminal

of Technology, but there was no reason to suspect that the night vision capacity of the group would differ from a random sample's capacity. All subjects were male, between the ages of 28 and 35. The experiment was conducted between the hours of 1030 and 1730 over a six-day period and took approximately 2.5 hours per subject to complete.

Procedure

The experiment can be broken down into four tasks:

1. Adaptation
2. Threshold/Frequency
3. Response
4. Comfort

The first two tasks were accomplished using the NVT only and provided baseline data of the absolute threshold and spatial frequency response of each subject. Task 3 used both the NVT and the pseudo-cockpit environment and provided data on the effect of the different light sources on the subject's absolute dark adaptation threshold and grating resolution. Task 4 relied solely on the pseudo-cockpit environment and provided data on the subject's luminance level preference for each of the two light sources (EL and INC).

Prior to the start of Task 1, the subject was shown the equipment, given a written explanation of the procedure (Appendix B), and signed a consent form (Appendix C).

Table 1 shows in outline form the procedure followed during the experiment. Each subject was instructed to press the response button when he could just distinguish the light for Task 1. Tasks 2 and 3 required the subject to press the response when he could just distinguish the light and press again when he could just distinguish the gratings. For Task 4, the subject was instructed to adjust the light level to where he would perform a normal flying mission.

TABLE 1

EXPERIMENTAL PROCEDURE

TASK 1: ADAPTATION

Sequence:

1. Lights turned out in room.
2. Timer starts.
3. Subject sets Variac to threshold and presses response button.
4. Time and Variac voltage recorded.
5. Subject returns Variac to zero setting and waits 30 seconds before repeating Step 3.
6. Subject continues for approximately 30 minutes.

TASK 2: THRESHOLD/FREQUENCY

Sequence:

1. Experimenter positions grating 1 into NVT.
2. Subject sets Variac to threshold and presses response button to record voltage.
3. Subject sets Variac to resolve gratings and presses response to record voltage.
4. Repeat Steps 2 and 3 eight times.
5. Repeat for each of five gratings.

TABLE 1--continued

TASK 3: RESPONSE

Sequence:

1. Experimenter randomly selects light source (EL or INC) at predetermined luminance level (~0.02 ftL).
2. Subject views pseudo-cockpit light area for 90 seconds.
3. Experimenter turns off light which starts timer.
4. Subject turns to NVT and adjusts Variac 2 to absolute threshold and presses response.
5. Elapsed time and voltage are recorded.
6. Subject adjusts Variac to resolve grating number 4 (10 cpd) and presses response.
7. Time and voltage are recorded--timer reset.
8. Repeat 1 through 7 eight times for each light source.

TASK 4: COMFORT

Sequence:

1. Experimenter randomly selects light source (EL or INC).
2. Subject adjusts cockpit Variac to comfort level and presses response.
3. Variac voltage and light source (EL or INC) are recorded.
4. Repeat 1 through 3 eight times for each light source.

CHAPTER III

ANALYSIS AND INTERPRETATION

Introduction

The purpose of this chapter is to provide the statistical techniques used to analyze the experimental data, explain the results of each portion of the experiment, and discuss those results.

Statistical Techniques

A single factor repeated measures design analysis of variance (ANOVA) was performed to determine the effects of different light sources (incandescent and electroluminescent) on the subject's absolute dark adaptation threshold and grating resolution threshold before and after light exposure. A one-way ANOVA with repeated measures was performed on the comfort portion of the experiment. The subject means for each condition were used as inputs to each cell. All results were tested at an alpha level of .05. A summary of the one-way ANOVAs with repeated measures is provided in Appendix H.

Results

The data for Task 1 dark adaptation and Task 2 resolution of each spatial frequency is graphed and shown

in Appendix D and E, respectively. The data for Task 3 response and Task 4 comfort portions of the experiment are tabulated in Appendices F and G.

The graphs of the dark adaptation curves approximate the classical work of Hecht and McFarland, but a direct comparison cannot be made due to the differences in apparatus and technique. The amount of noise in the system did not allow for acceptable curve fitting of the data. The graphs show considerable variability between subjects, e.g., Subject 1 attained his threshold level of approximately 1×10^{-6} ftL within 12 minutes, whereas Subject 7 only required 5 minutes to attain the same threshold level. The threshold levels varied between subjects from 3×10^{-7} ftL to 8×10^{-6} ftL.

The subjects mean values of luminance threshold for resolution of spatial frequencies varied considerably. Resolution of the 10 cycles per degree grating required an average luminance level of 0.004 ftL for Subject 7, but 0.019 for Subject 2. The respective standard deviations are 0.009 and 0.004.

The results of the absolute threshold portion of Task 2 and Task 3 in the experiment relate to research Question 1 found in Chapter I. The computerized results of the ANOVA are provided as Appendix I and the F- ratios and

their probabilities are listed in Table 2. The results indicate that the null hypothesis cannot be rejected, and led to the conclusion that an EL light source affects the dark adaptation threshold of the human eye in the same manner as an incandescent light source at the .05 alpha level.

TABLE 2

ABSOLUTE THRESHOLD RESULTS

ANOVA	F- Ratio	Probability
Before vs INC vs EL	1.192	0.3585
Before vs INC	1.107	0.3277
Before vs EL	1.629	0.2426
INC vs EL	0.036	0.8549

The results of the grating resolution portion of Task 2 and Task 3 in the experiment relate to research Question 2 found in Chapter I. The computerized results of the ANOVA are provided in Appendix J and the F- ratios and their probabilities are listed in Table 3.

The results do not allow for the rejection of the null hypothesis, and led to the conclusion that the two light sources affect grating resolution threshold in the same manner. The F- probability of the incandescent versus electroluminescent ANOVA of 0.0203 seems to contradict all

TABLE 3

GRATING RESOLUTION F- RATIOS
AND PROBABILITIES

ANOVA	F- Ratio	Probability
Before vs INC vs EL	2.131	0.1812
Before vs INC	2.834	0.1308
Before vs EL	1.435	0.2652
INC vs EL	8.331	0.0203

previous results. Therefore, a Siegel-Tukey Test was performed on that particular data. The assumption of normality was relaxed, and the test was conducted with the hypothesis as follows:

H_o: VAR(INC) = VAR(EL)

H_a: VAR(INC) $\neq$ VAR(EL)

The test was conducted at the .05 alpha level and the results do not allow for the rejection of the null hypothesis. The calculations are provided in Appendix K.

The results of Task 4, the comfort portion of the experiment, relate to the third hypothesis found in Chapter I. The computerized results of the one-way ANOVA are provided in Appendix L. The F- ratio of 11.531 and P(F) 11.531 = .0094 led to the rejection of the null hypothesis, and the conclusion that individuals selected lower

luminance levels with the EL light source than with the incandescent light source. The ratio of incandescent to electroluminescent averaged 1.4. This indicates that the subjects selected 40 percent more light for their comfort when using the incandescent light source.

Discussion

A cursory look at the data provided in Appendix D indicates the wide variability of both absolute threshold and grating resolution between individual subjects. Subject 7 was not included in the analysis of the entire experiment. It was learned the subject had been diagnosed as having Aides Pupils. Aides Pupils is a condition where the pupils of the eye are fixed and do not respond to changes in light levels. Though Subject 7 met the initial criteria of 20/20 vision and a rated Air Force officer, it was felt the abnormality of Aides Pupils was sufficient to disqualify his results.

Subject 6 was not included in the analysis of the absolute threshold portion of the experiment. His data indicates he was two orders of magnitude different than any other subject in the posttreatment portion of the experiment. Apparently, exposure to the EL and INC light sources completely destroyed his rod vision, and he was operating with the use of his cones to detect light. It is also interesting to note Subject 6's dark adaptation curve

(Appendix D) is one of the higher curves encountered in this experiment.

The lack of evidence to reject the null hypothesis for the first two research questions is not surprising. The eye reacts to a photon of light of a particular wavelength, regardless of the source of light. The rejection of the null hypothesis for research Question 3 was unexpected. A recheck of the experimental apparatus revealed that the photometer was measuring an infrared component with the incandescent light source. This explains about 8 percent of the difference, but still leaves over 30 percent to be explained. The dynamics of the equipment as it relates to the curves of the EL and INC light sources may be another source of the differences found in this experiment.

The dynamics of the equipment refers to the fact that the Variacs used were linear in nature and controlled the voltage for each light source. As can be seen by Figure 8, the electroluminescent light source was somewhat linear with respect to voltage, but the incandescent source was not linear. This may explain the remaining differences found in this experiment.

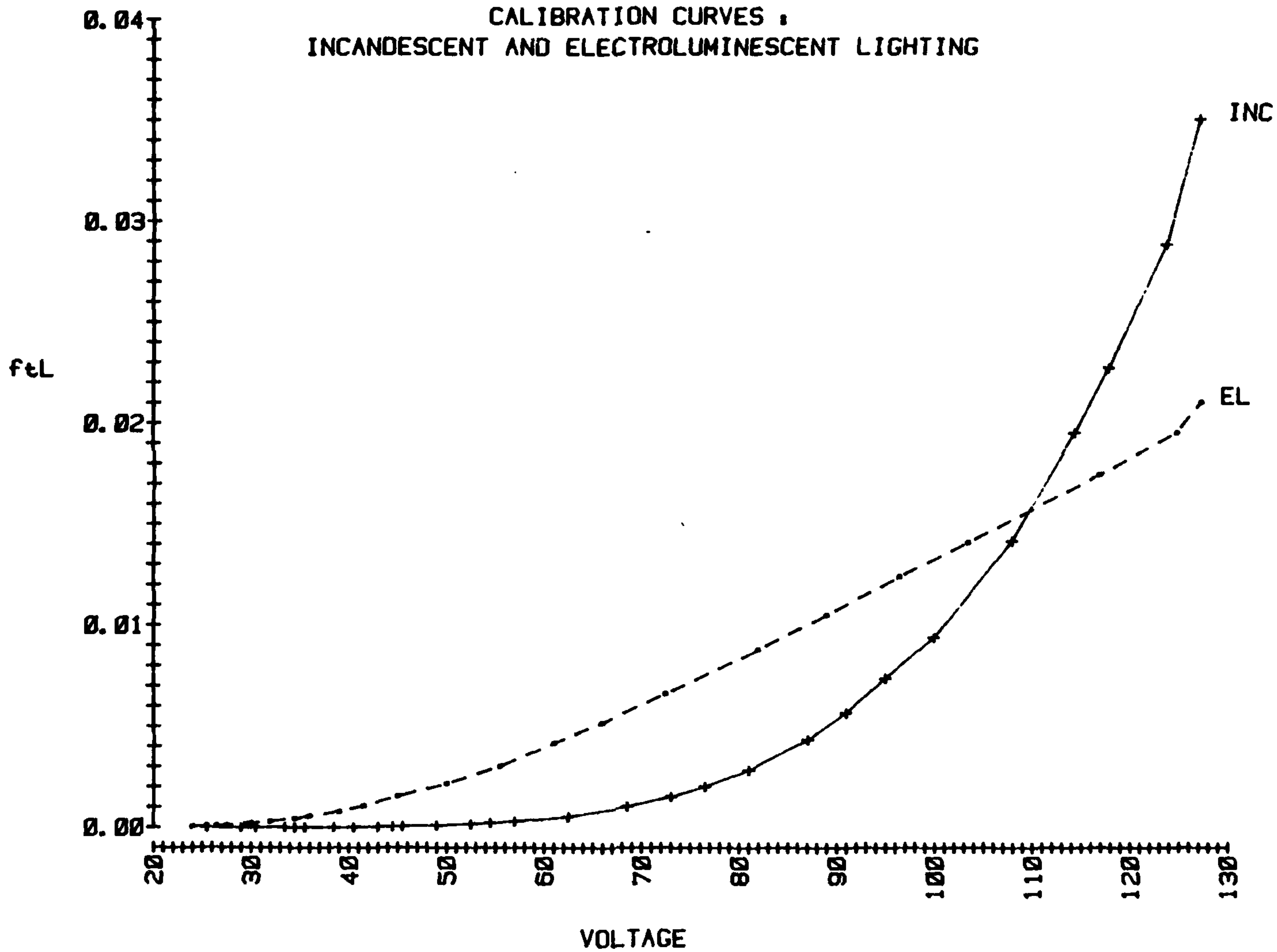


Figure 8. Calibration Curves

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Introduction

In this chapter, the findings discussed in Chapter III are evaluated in light of the initial hypotheses specified in Chapter I. Each of the hypotheses is restated and considered below. Because this research effort was a preliminary investigation into the differences of incandescent versus electroluminescent light sources, some recommendations for future study are provided.

Conclusions

The first hypothesis dealt with the absolute threshold of dark adaptation of the human eye. It stated:

> An EL light source affects the adaptation threshold of the human eye in the same manner as an incandescent light source.

The experimental data and the subsequent analysis provided no evidence to reject the above-stated hypothesis at the .05 alpha level.

The second hypothesis was concerned with the resolution of a square wave grating of a predetermined spatial frequency. It stated:

> An EL light source affects the ability of the human eye to resolve a square wave grating at a predetermined spatial frequency in the same manner as an incandescent light source.

The experimental data and subsequent analysis again provided no evidence to reject this hypothesis at the .05 alpha level. The significant difference noted when an ANOVA was conducted on the EL versus INC portion of the grating resolution portion of the experiment was attributed to the very large differences between subjects. To compensate for the large disparity, additional analysis relaxed the assumption of a normal population and tested the equality of the variances. Analysis established that no significant differences were present. Based on these findings, it was concluded that the ability of the human eye to resolve a square wave grating is not dependent on the type of light source.

The final hypothesis was concerned with a subjective evaluation of the amount of light required to fly a normal mission by rated Air Force officers. It stated:

> Rated Air Force personnel select the same or greater cockpit luminance levels when using an EL light source than when using an incandescent light source.

The experimental data and subsequent analysis led to the rejection of the above-stated hypothesis. A significant difference was noted between the two light sources. An interesting discovery not tested during this experiment was

the difference in luminance levels based on aeronautical rating. The three pilots in the group invariably selected lower luminance levels than did the navigators. This fact may be of importance to aircraft cockpit lighting designers, especially in two-place cockpits such as the FB-111.

Recommendations

This study has been an initial investigation of the claims that electroluminescent light is somehow perceived differently by the human eye than is incandescent light. Therefore, it is difficult to generalize the findings herein over the wide range of the entire cockpit luminance problem. However, even though the actual scope of this study was confined to a small population, certain recommendations can be made which could aid in defining the overall cockpit lighting criteria.

Research completed for this study indicates that EL light should not be selected for cockpit lighting based on its effect on dark adaptation alone. There may be many other reasons, i.e., power consumption, cost, life span, weight, etc., to select EL light, but its effect on dark adaptation and square wave grating resolution is no different than incandescent lighting.

With respect to the comfort portion of the test, additional research to control the dynamics of the experiment may resolve the differences found in this experiment. One suggestion for further study is to preset the luminance of the incandescent light source and have the subject adjust the EL source to match the luminance levels. In this manner the effect of the two different luminance curves and the relative positioning of the Variac could be eliminated as a cause of those differences.

An additional area for further research is the difference in comfort levels between pilots and navigators. Research into this area may provide verification of the differences found in this preliminary study. This effect may be of some importance in designing future aircraft cockpit lighting systems.

The substantial variability that exists between subjects is worthy of note even in this small sample size. Additional research is required to determine the extent and relevance of this variability as it applies to different light sources.

APPENDICES

APPENDIX A

DEFINITION OF SPATIAL FREQUENCY

SPATIAL FREQUENCY

A square wave grating is a repeated sequence of light and dark bars. The width of one light and one dark bar of a grating is one cycle or the period of the grating. The reciprocal of the period is the spatial frequency--the number of cycles of the grating that occur over a specified distance. The spatial frequency of an object can be expressed in cycles per degree (cpd) of visual angle. The square wave grating relates to an individual's visual acuity. For example, a square wave grating consisting of 80 cycles per inch equals 10 cycles per degree. Ten cycles per degree is equivalent to 3 minutes of arc or 20/60 vision.

APPENDIX B

EXPERIMENTAL PROCEDURE

EXPERIMENTAL PROCEDURE

Dark Adaptation of Rated Air Force Officers Using Electroluminescent versus Incandescent Light Sources

You are invited to participate in an experiment entitled, "Dark Adaptation of Rated Air Force Officers using Electroluminescent versus Incandescent Light Sources." We hope to study and measure any difference in these lighting systems.

If you decide to participate, you will be asked to take part in three phases of the experiment. The first phase will be standard dark adaptation measurements using the same type of device used in an ophthalmologist's office. You will be asked to sit in a dark room for about 30 minutes and asked to identify a striped slide as your eyes adapt to the dark.

The second phase will consist of spatial threshold measurements. You will be asked to view a slide under dark environment conditions. The slide will be retro-illuminated with the amount of light slowly increasing. You will be asked (a) when you see any luminance, and then (b) to identify the target on the slide. The light will then be decreased to the initial conditions and the measurements repeated.

In the third phase you will be asked to sit in front of a simulated cockpit panel and increase the lighting until you feel it to be at a comfortable working level, i.e., you can readily identify the information on the dials and gauges. You will then be measured for dark adaptation as before.

Your confidentiality as a participant in this program will be protected. Your name will not be revealed without your written permission. Statistical data collected during the test program may be published in scientific literature without identifying individual subjects. You will be asked to participate for one session that will last no more than 2 hours with approximately 30 minutes for initial dark adaptation. There will be about a 5 minute break each half hour.

You will receive no monetary benefits for participating in the study. No alternative exists to obtain the required information. Your decision to participate will not prejudice your future relations with the Air Force Aerospace Medical Research Laboratory. If you decide to participate, you are still free to withdraw your consent and to discontinue participation at any time without prejudice. If you

have any questions, we expect you to ask us. If you have additional questions later, Dr. Lee Task, Lt. Col. Genco, or Capt. Blouin (255-6623) will be happy to answer them. Any medical questions will be referred to Dr. Wolf.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP.

__________ ______________________

Date VOLUNTEER'S INITIALS

APPENDIX C

CONSENT FORM

CONSENT FORM

Dark Adaptation of Rated Air Force Officers Using Electroluminescent versus Incandescent Light Sources

I, ______________________________, having full capacity to consent, do hereby volunteer to participate in a research study entitled, "Dark Adaptation of Rated Air Force Officers Using Electroluminescent versus Incandescent Light Sources" under the direction of Dr. Lee Task, Lt. Col. Lou Genco, and Capt. George K. Blouin. The implications of my voluntary participation, the nature, duration, and purpose, the methods and means by which it is to be conducted, and inconveniences and hazards which may reasonably be expected have been explained to me by ______________________________ and are set forth on the reverse side of this agreement, which I have initialed. I have been given the opportunity to ask questions concerning this research project, and any such questions have been answered to full and complete satisfaction. I understand that I may at any time during the course of this project revoke my consent, and withdraw from the project without prejudice.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

AM
PM
____
Signature Date Time

I was present during the explanation referred to above, as well as the volunteer's opportunity for questions, and hereby witness the signature.

____
Signature Date

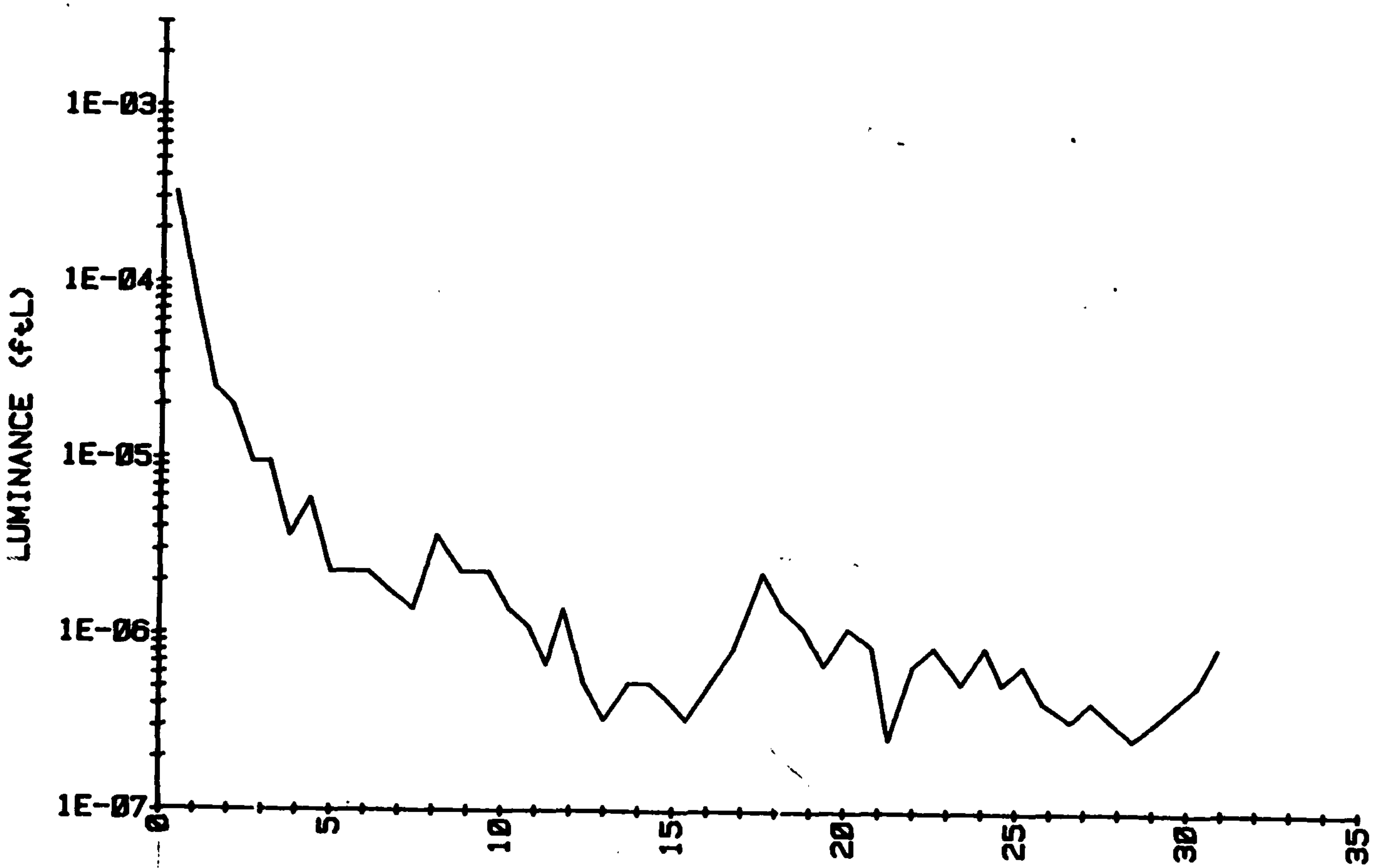
I have briefed the volunteer and answered questions concerning the research project.

____
Signature Date

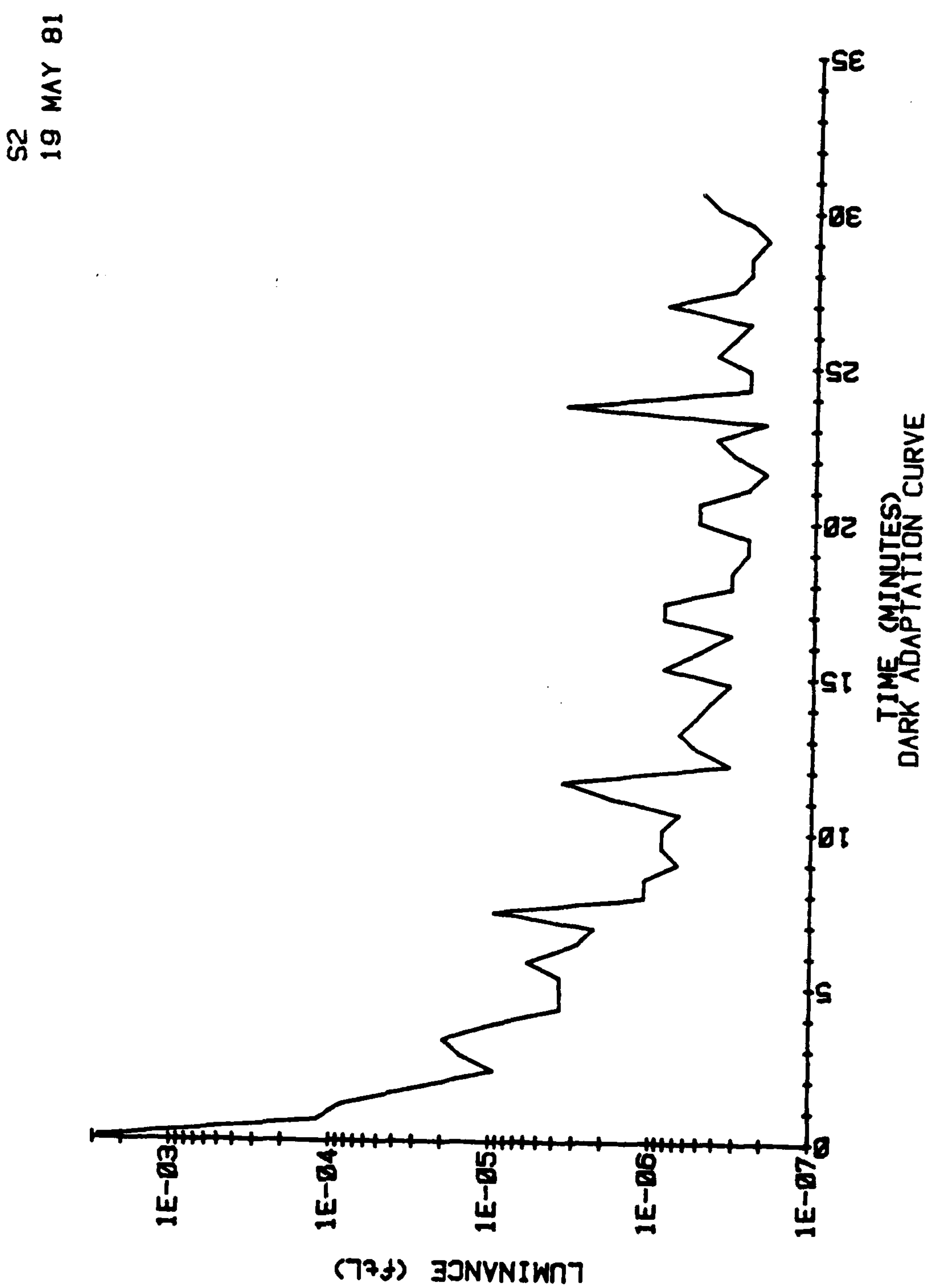
APPENDIX D

DARK ADAPTATION CURVES

S1
19 MAY 81



DARK ADAPTATION CURVE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19 MAY 81
LUMINANCE (ftL)
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1E-04
1E-05
1E-06
1E-07
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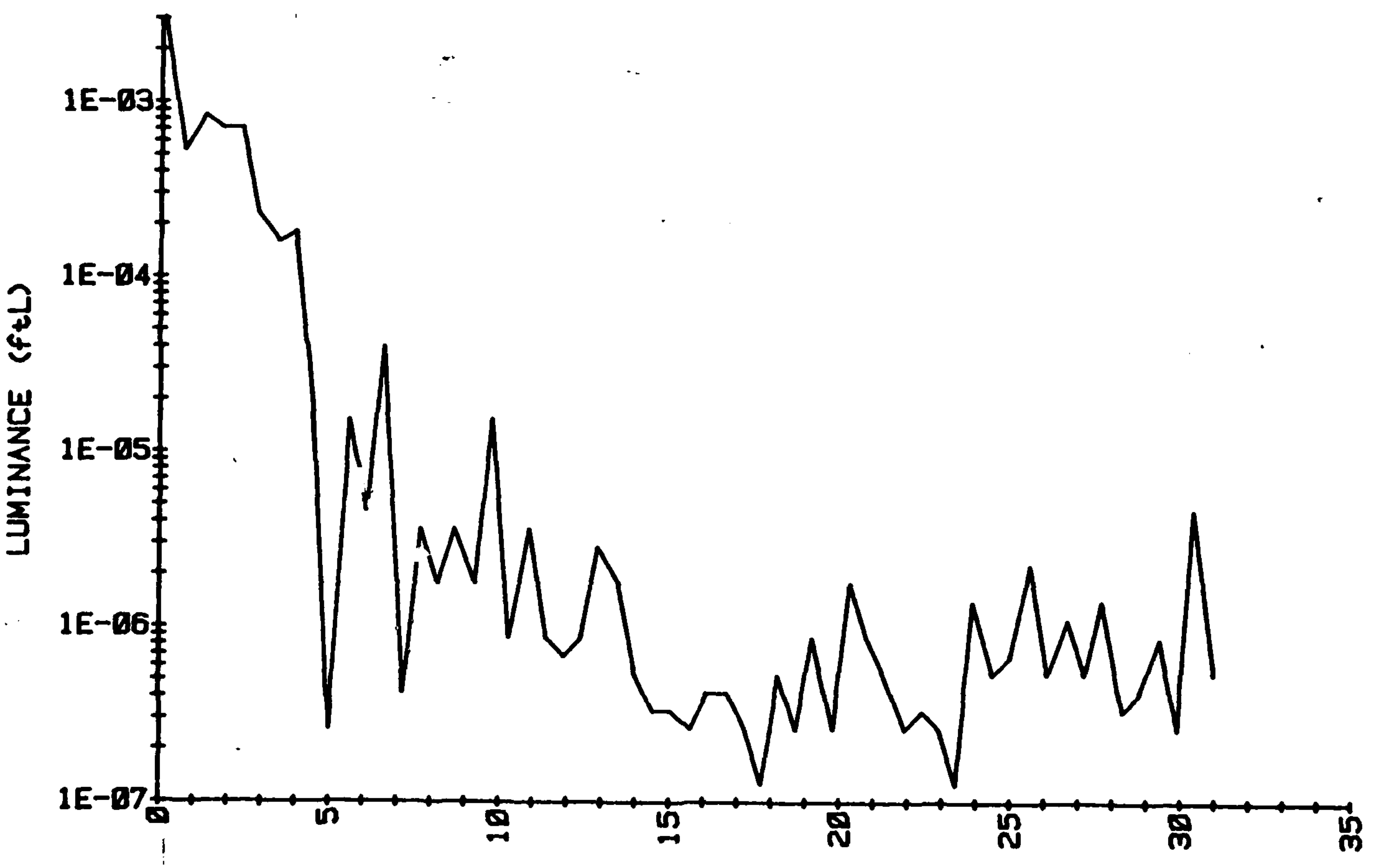
5
10
15
20
25
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE



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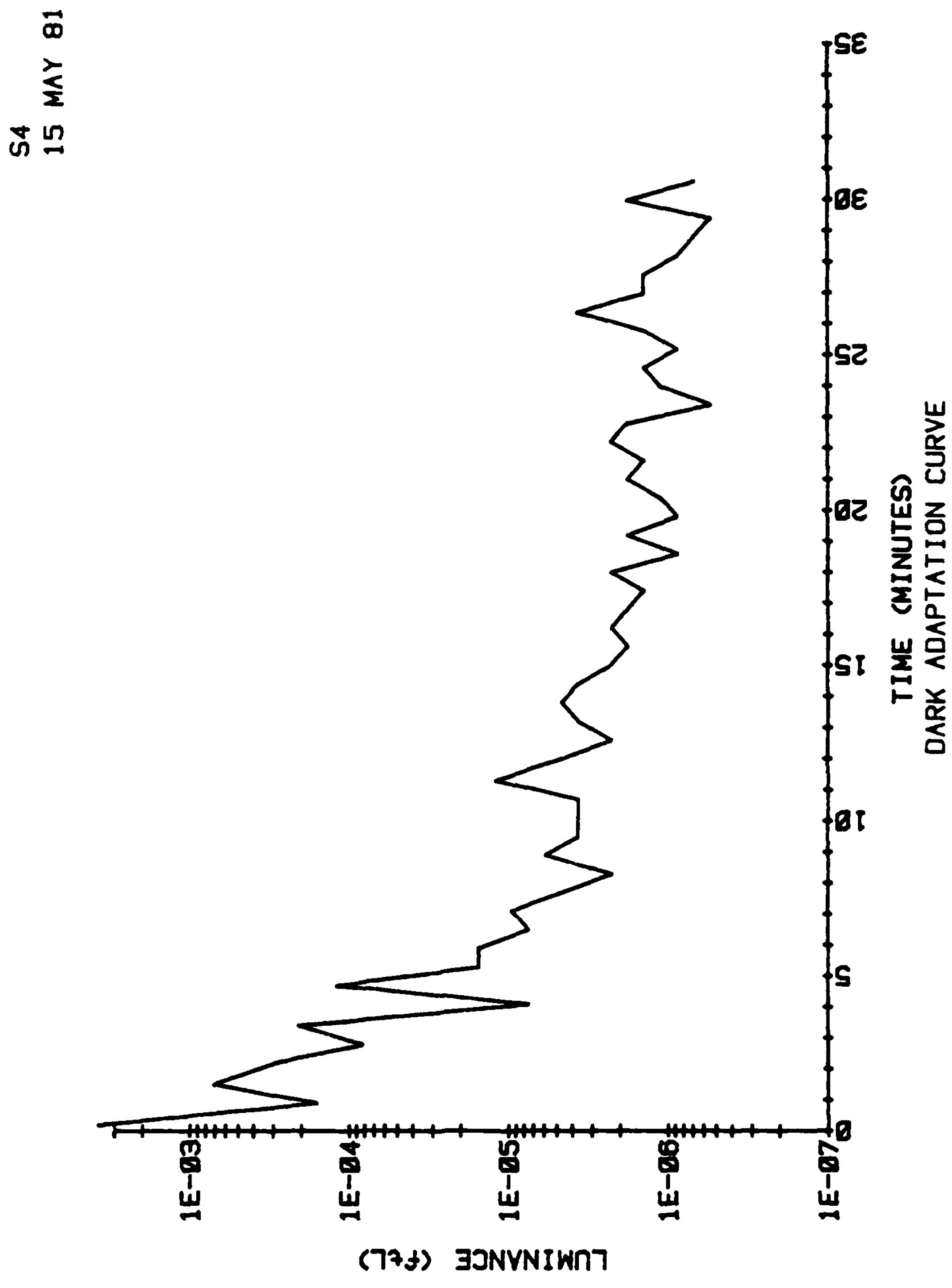
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1E-04
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1E-07
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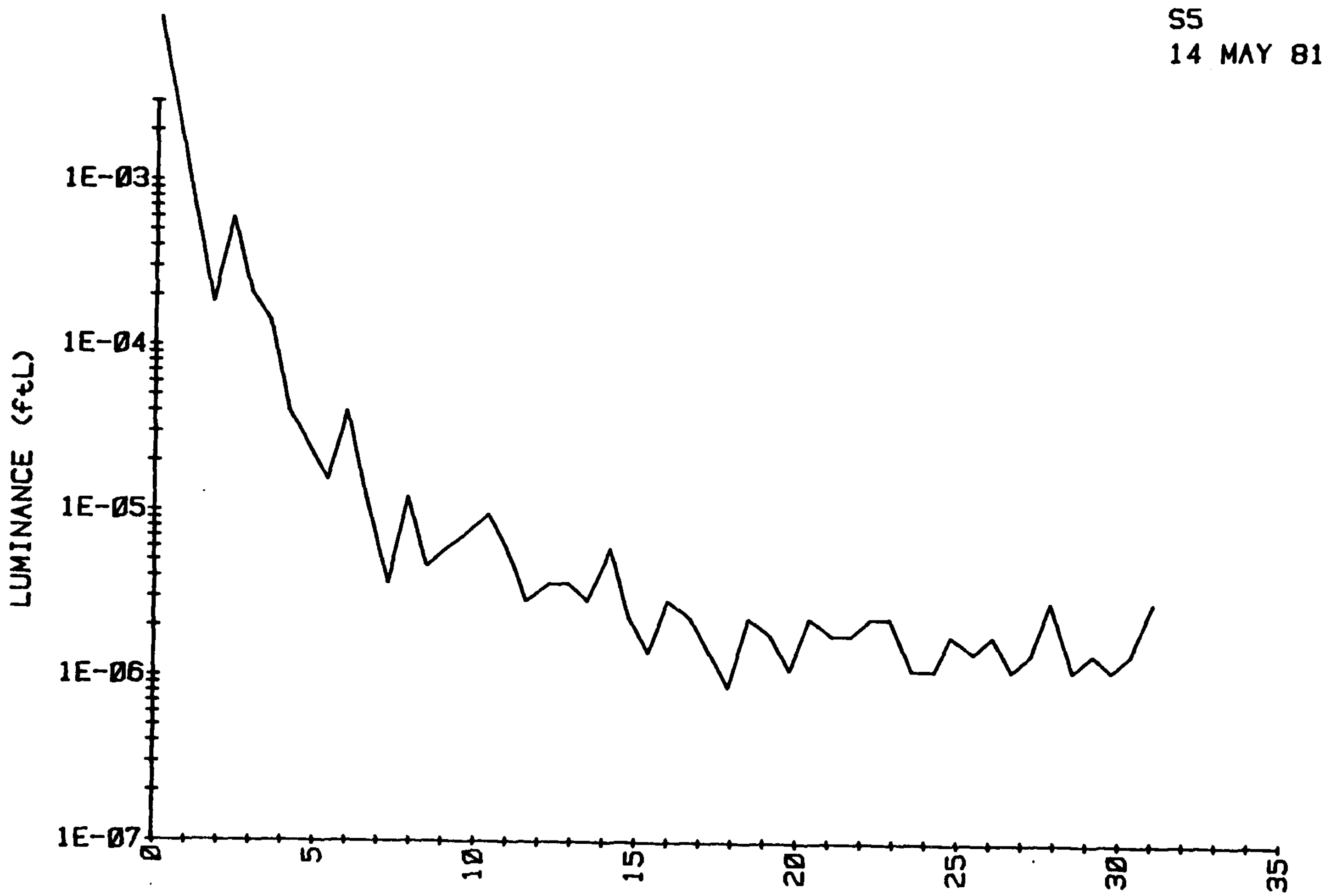
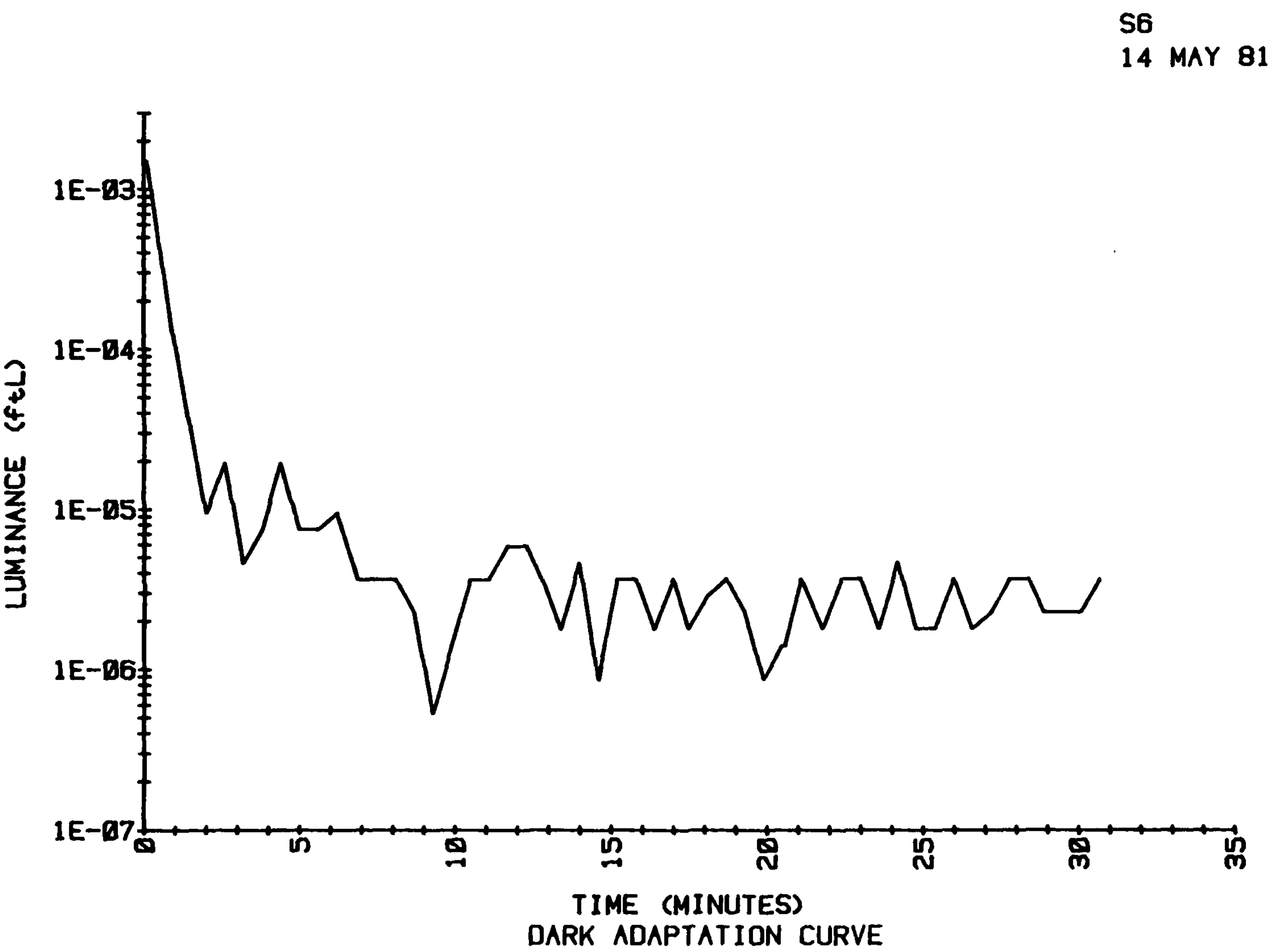
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE



TIME (MINUTES)
DARK ADAPTATION CURVE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1E-05
1E-06
1E-07
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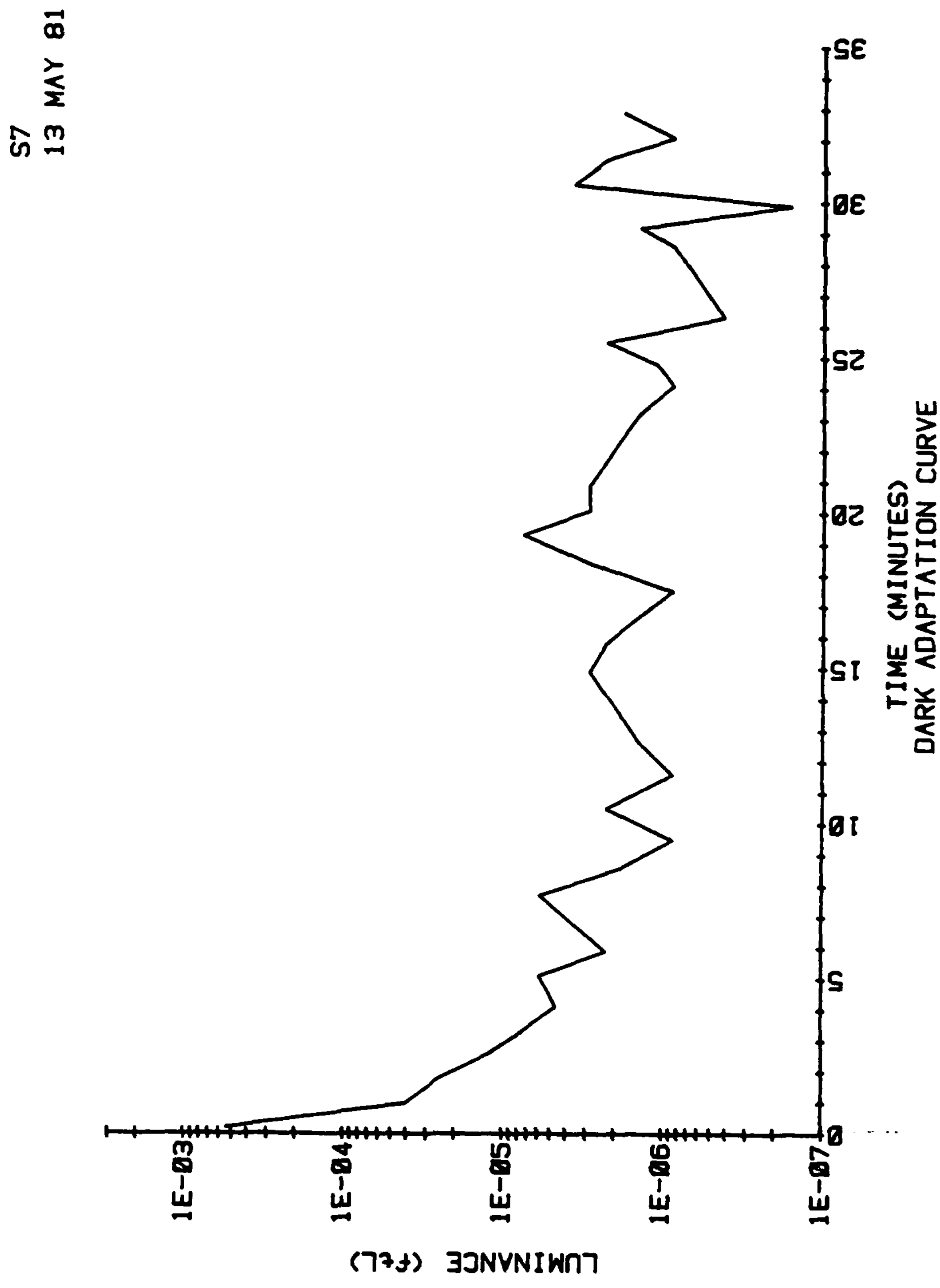
10
15
20
25
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE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LUMINANCE (ftL)
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1E-05
1E-06
1E-07
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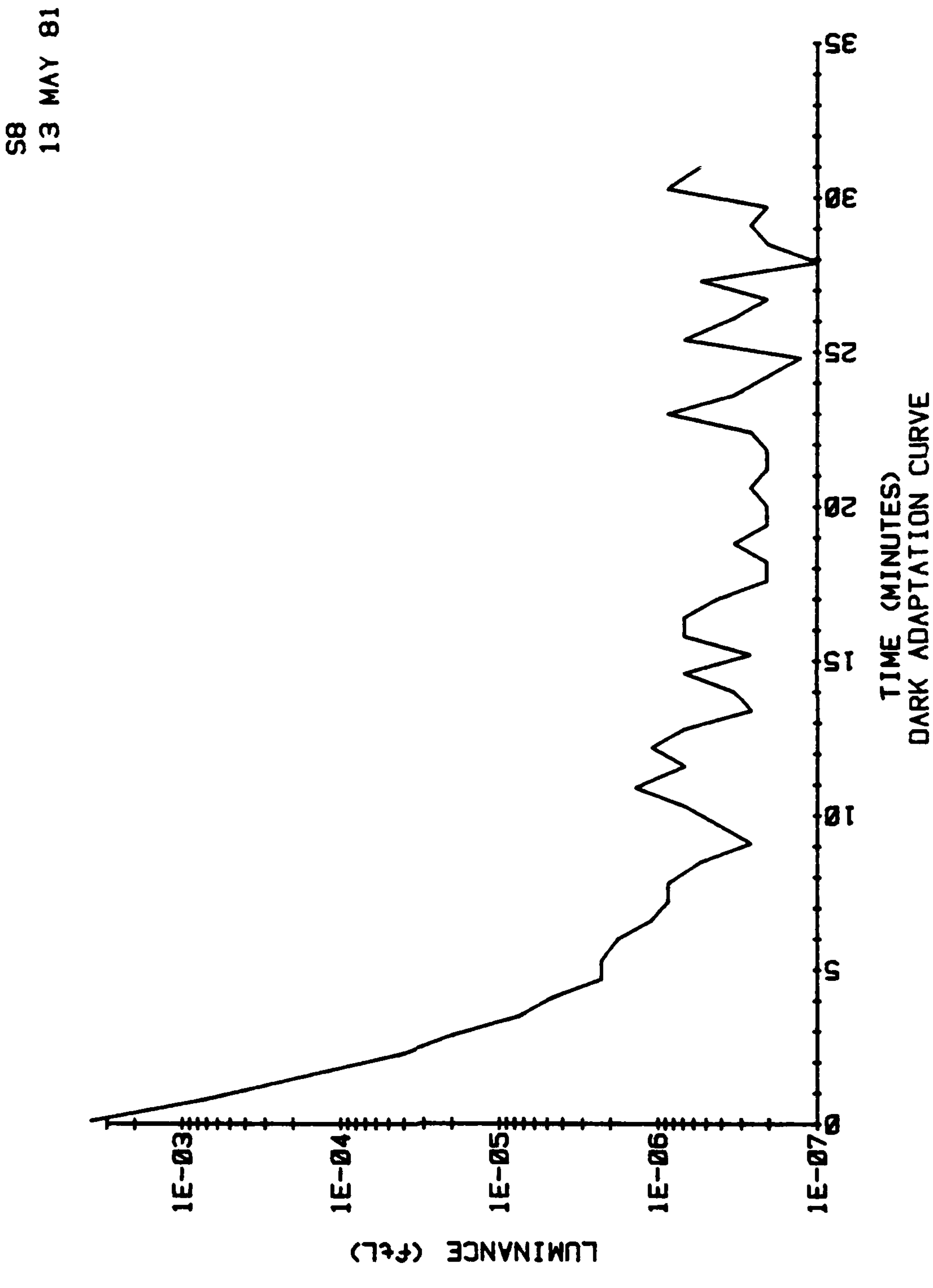
5
10
15
20
25
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE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1E-07
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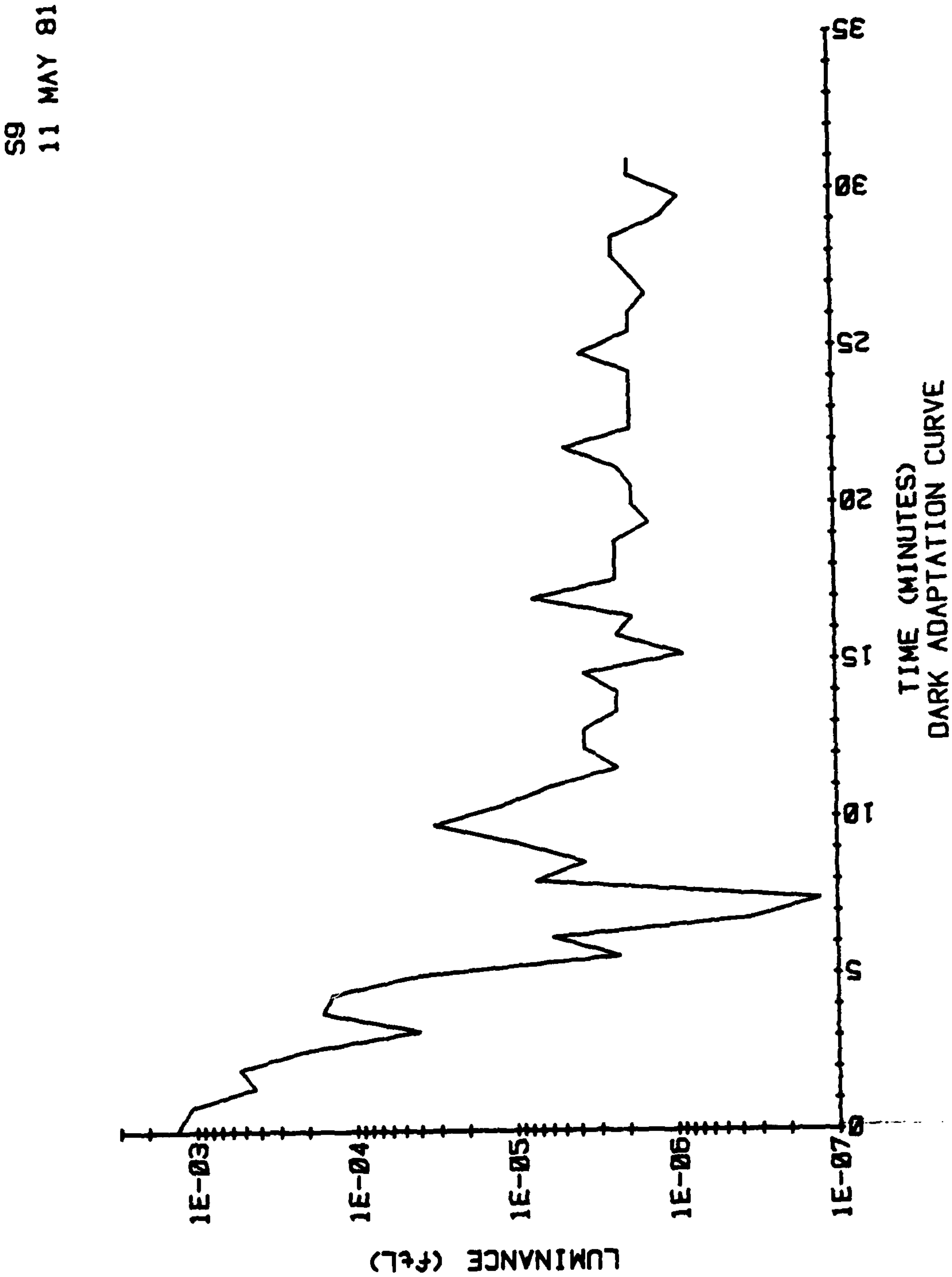
20
25
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE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1E-07
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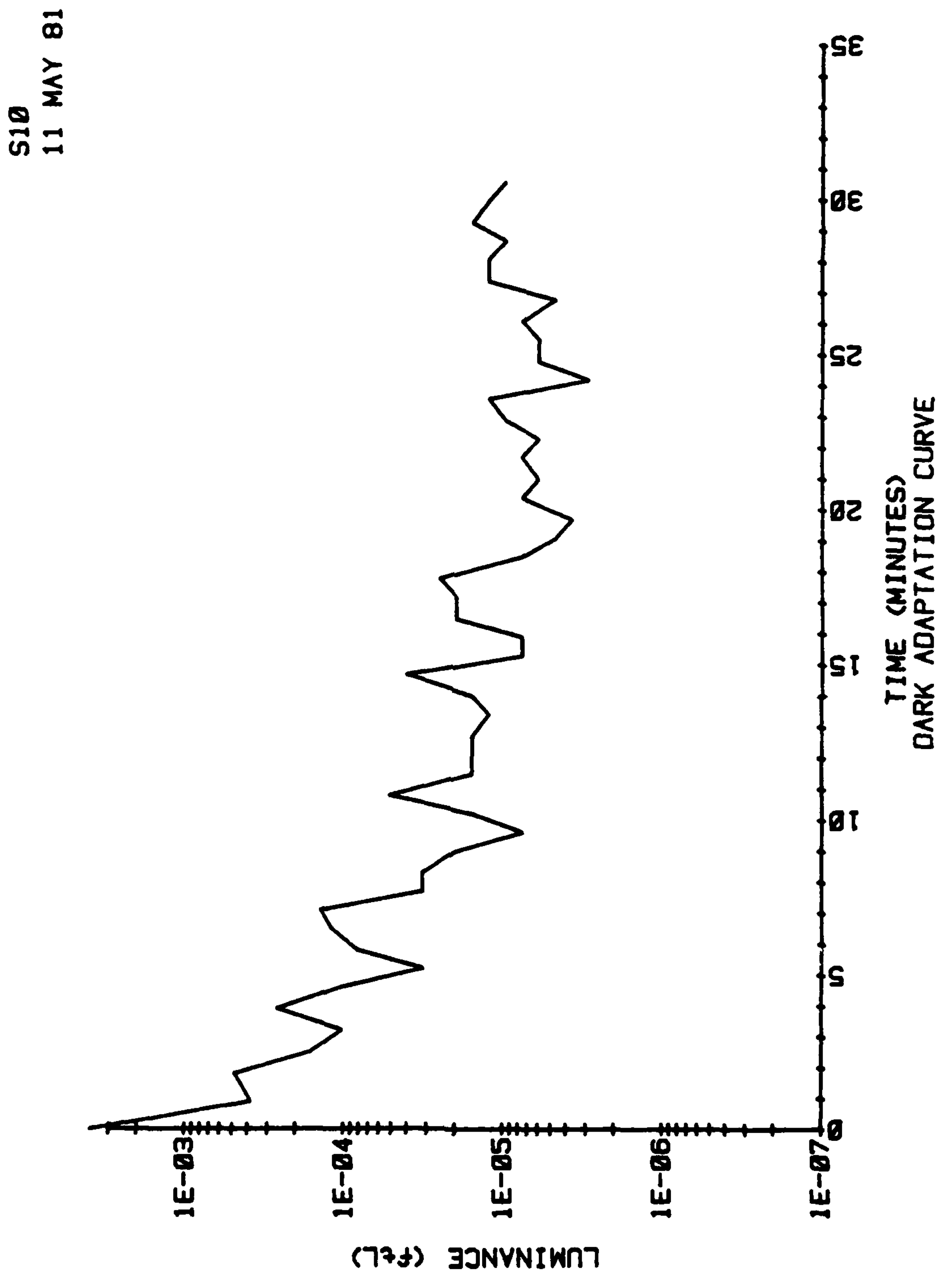
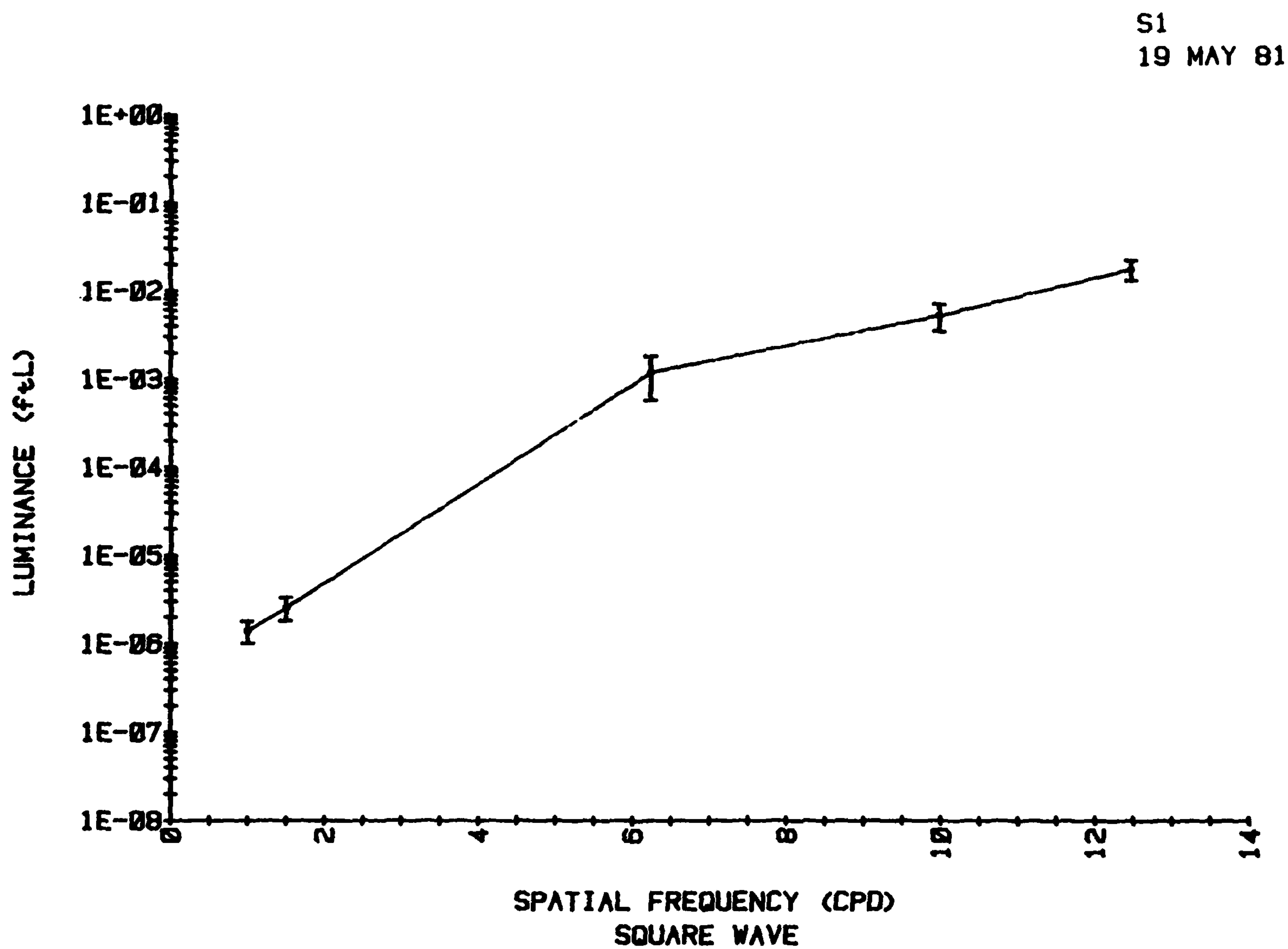
30
35
TIME (MINUTES)
DARK ADAPTATION CURVE



S1Ø
11 MAY 81
LUMINANCE (fL)
1E-Ø3
1E-Ø4
1E-Ø5
1E-Ø6
1E-Ø7
Ø
5
1Ø
15
2Ø
25
3Ø
35
TIME (MINUTES)
DARK ADAPTATION CURVE

APPENDIX E

SQUARE WAVE SPATIAL FREQUENCY GRAPHS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1E-03
1E-04
1E-05
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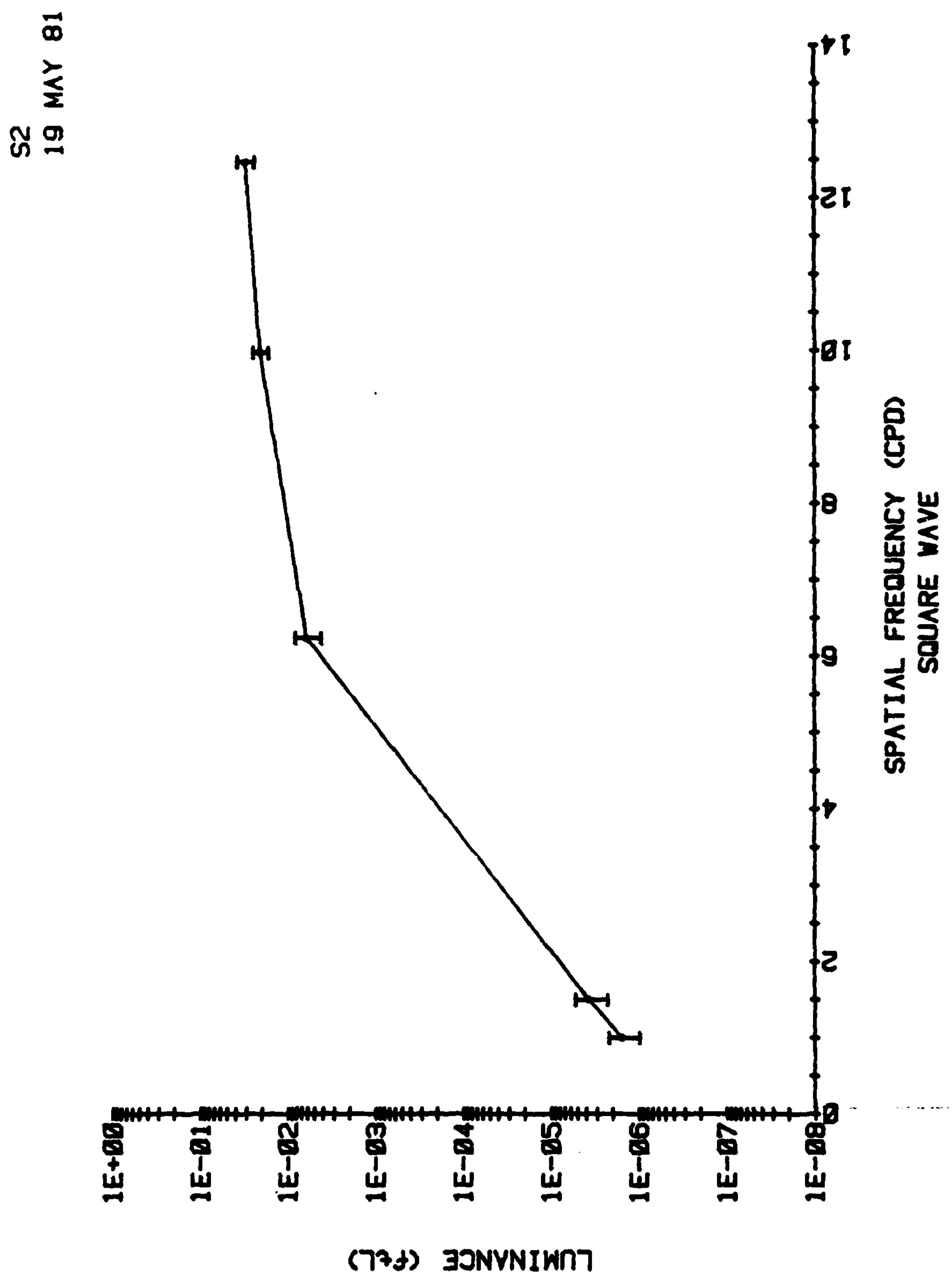
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE



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SQUARE WAVE
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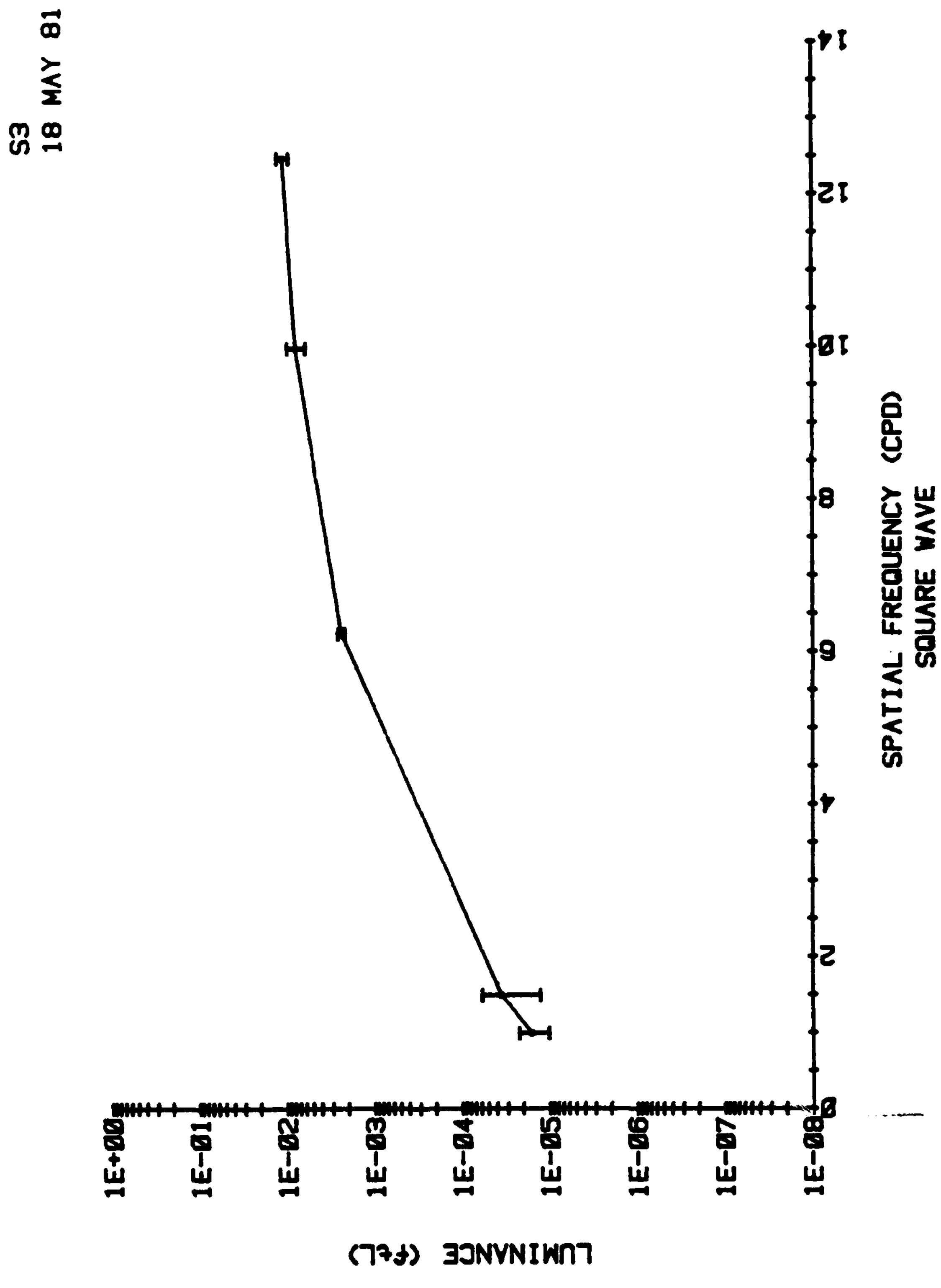
4
6
8
10
12
14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1E-04
1E-05
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1E-08
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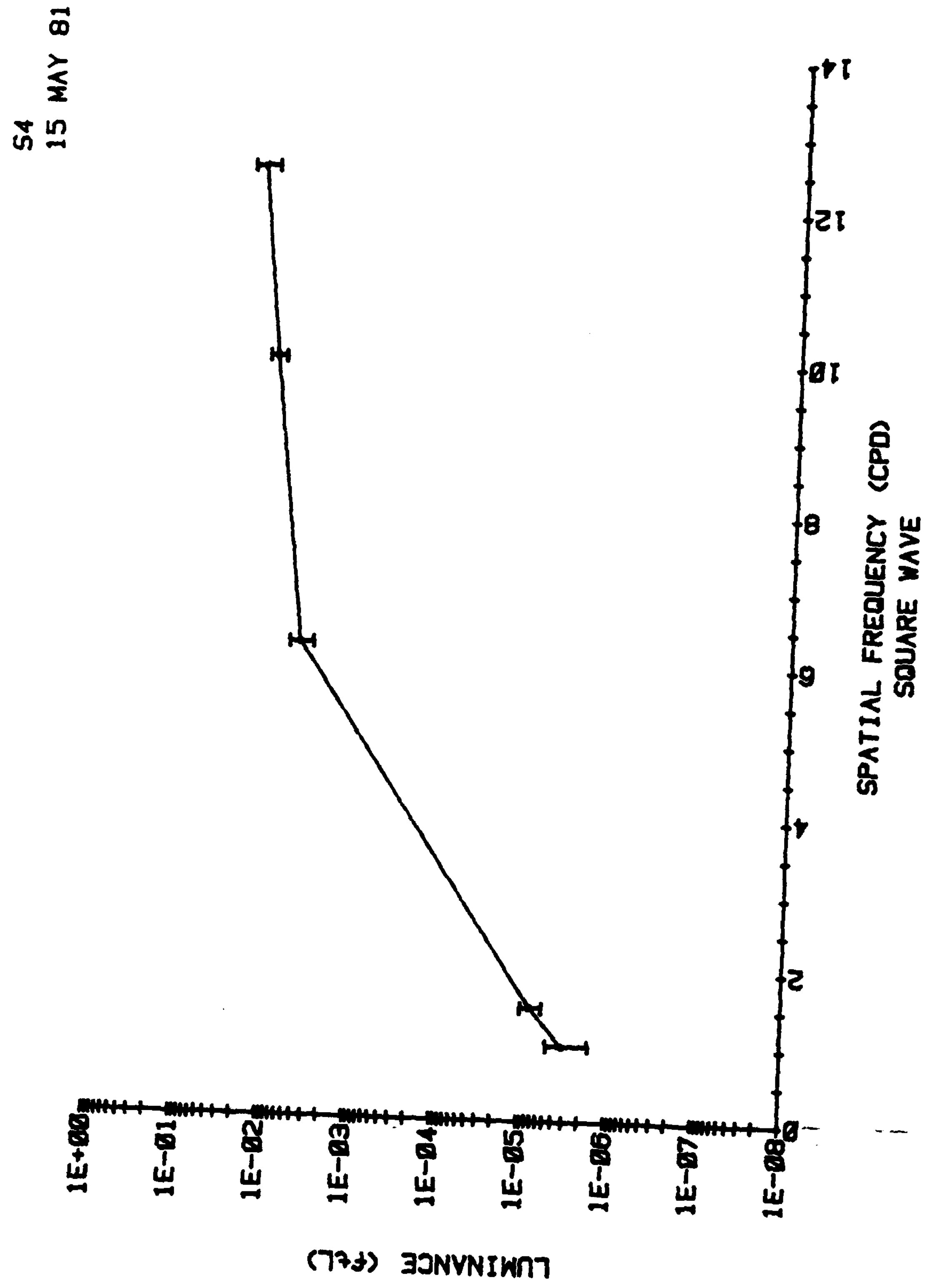
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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15 MAY 81
LUMINANCE (ftL)
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1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
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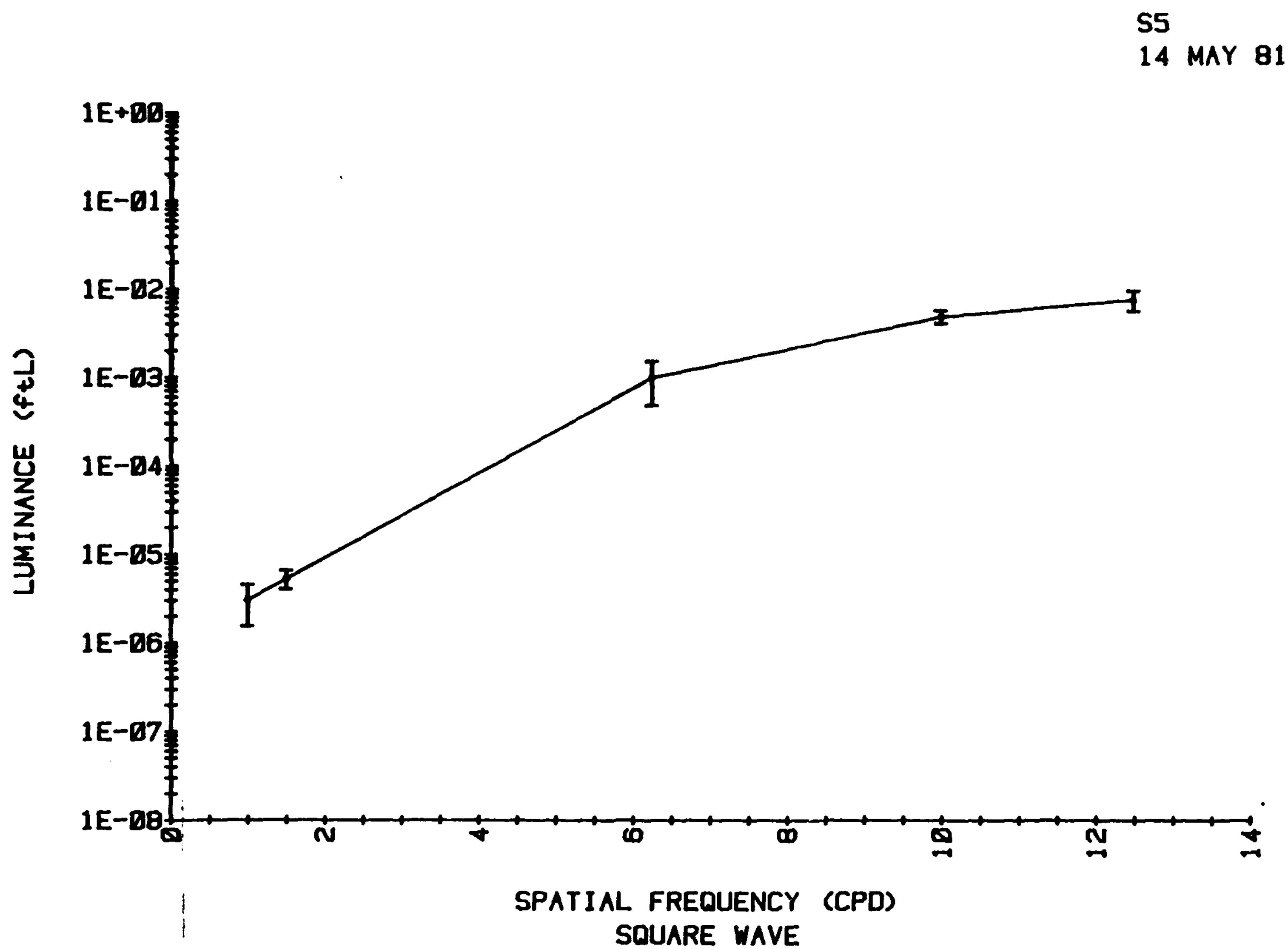
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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1E-07
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LUMINANCE (ftL)
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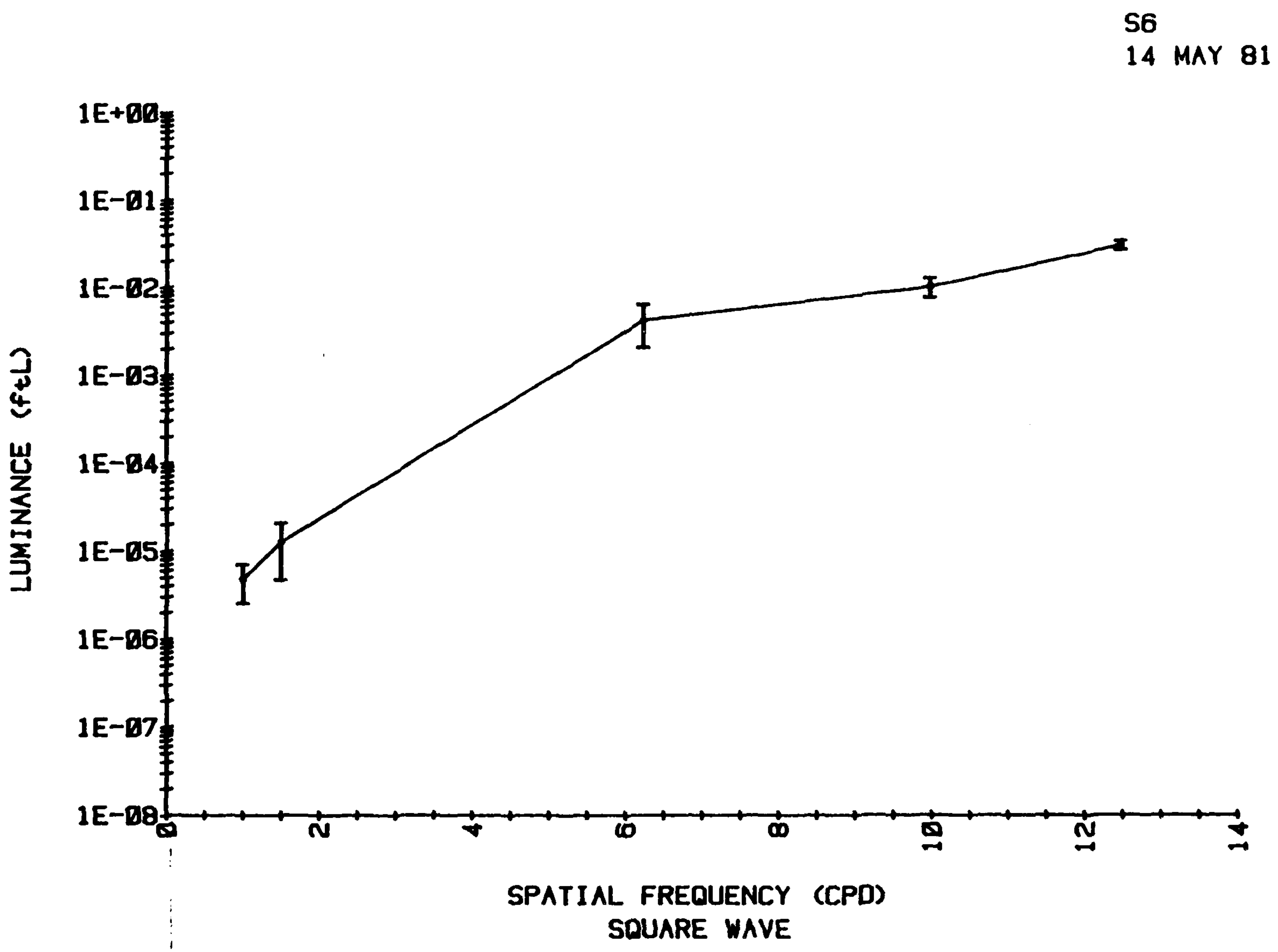
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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4
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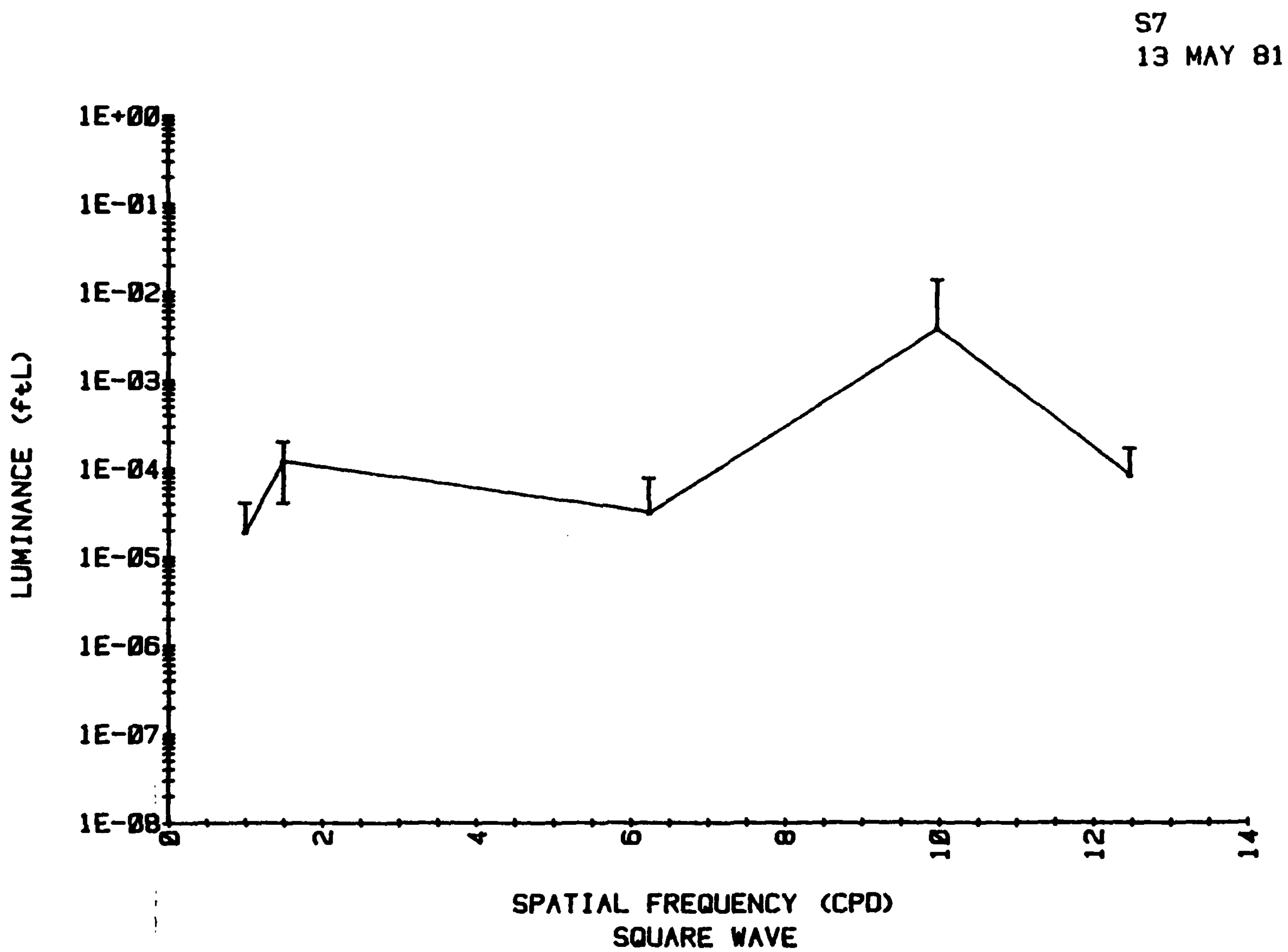
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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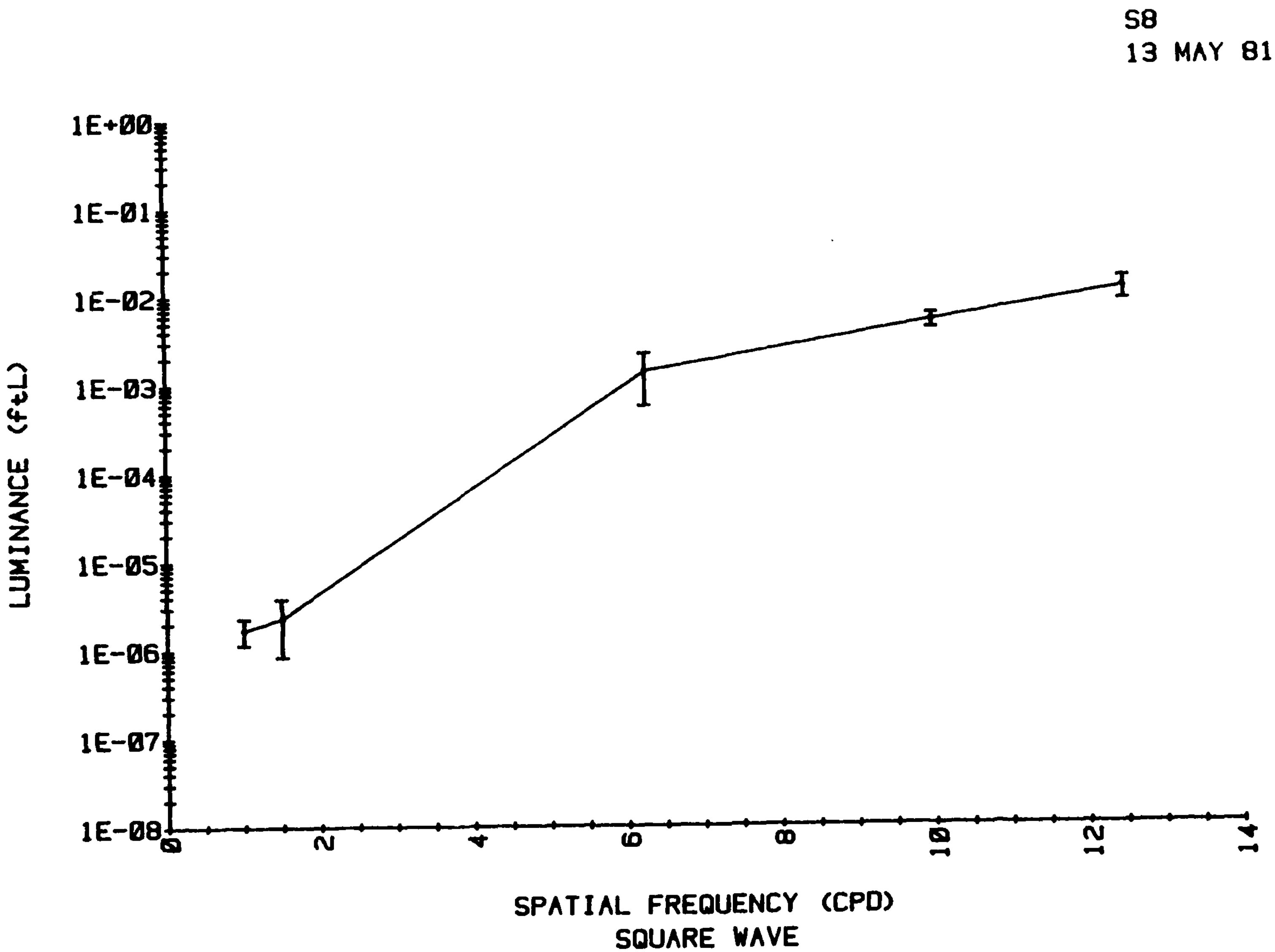
1E-06
1E-07
1E-08
LUMINANCE (ftL)
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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1E-07
1E-08
LUMINANCE (ftL)
0
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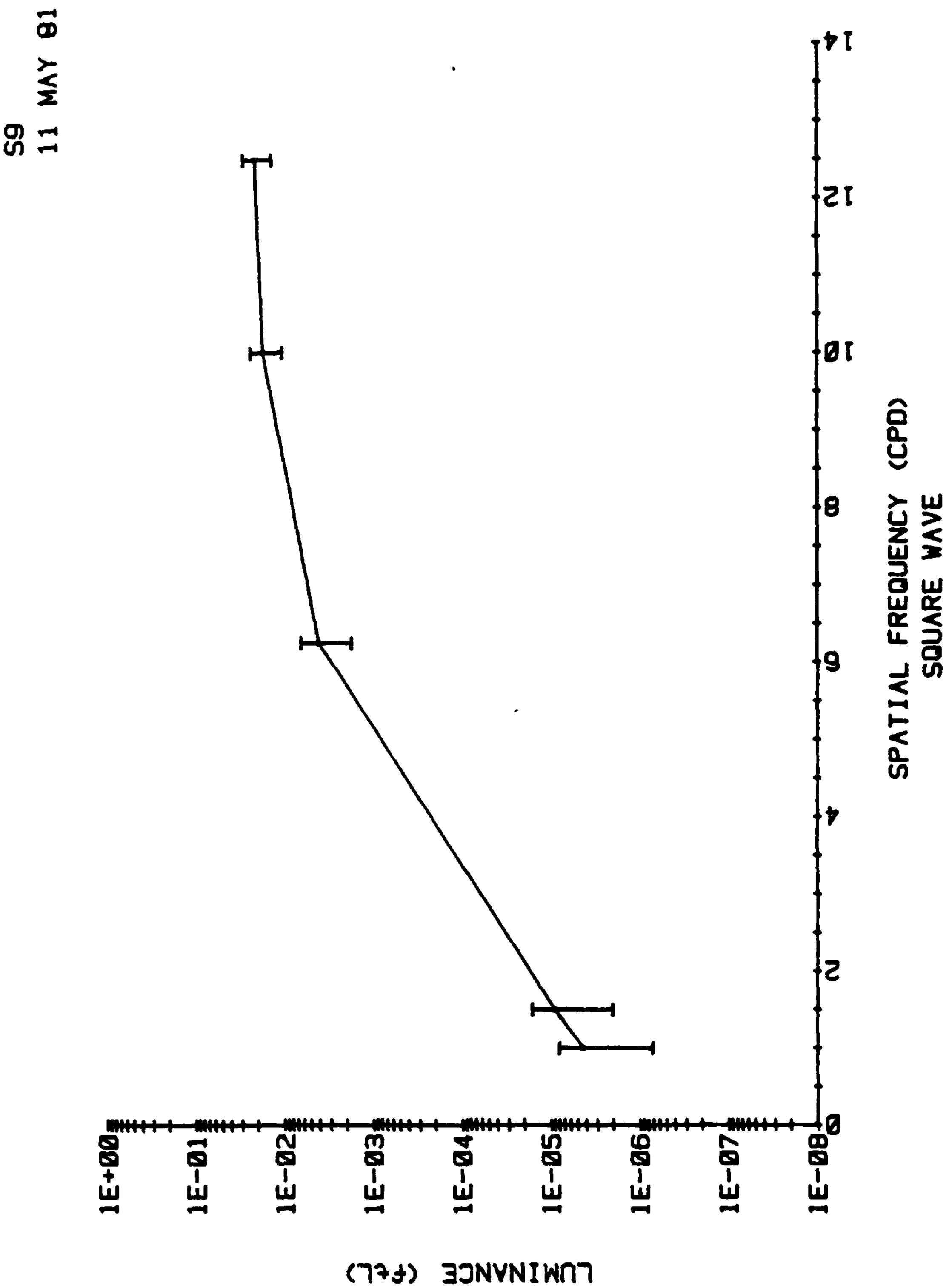
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE



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LUMINANCE (fL)
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1E-04
1E-05
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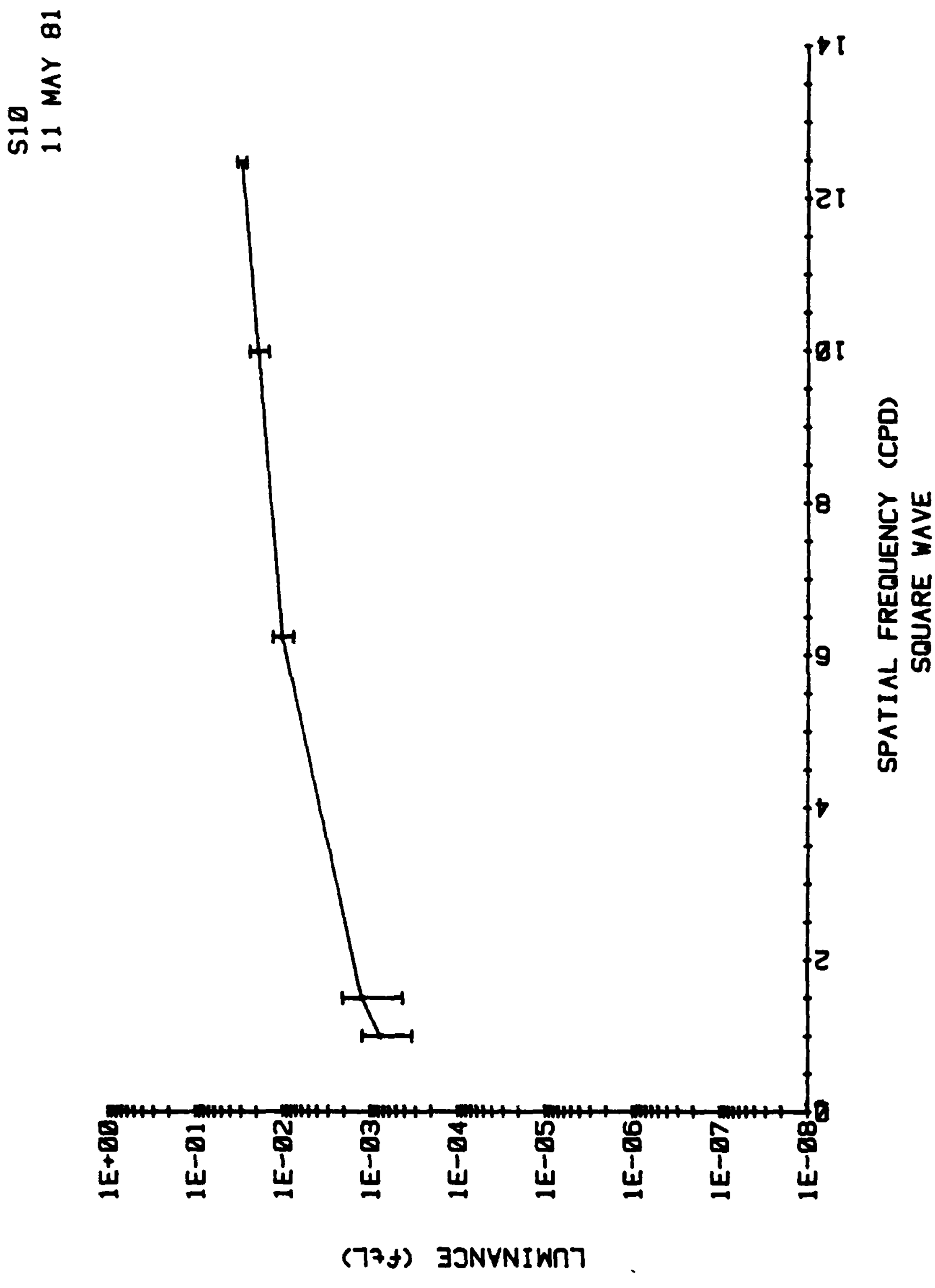
1E-07
1E-08
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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LUMINANCE (fL)
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1E-03
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1E-05
1E-06
1E-07
1E-08
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE

APPENDIX F

TASK 3
RESPONSE DATA

ABSOLUTE THRESHOLD

10 cpd

Subject	Pretreatment		Posttreatment			
			EL		INC	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1	5.323	4.340	3.33	2.62	2.94	2.84
2	21.30	55.56	87.75	57.39	70.42	90.53
3	74.99	109.40	50.0	46.99	28.66	15.33
4	4.793	3.203	19.67	20.10	21.69	16.11
5	2.793	1.434	18.96	14.38	22.08	14.06
6	2.851	1.396	380.75	434.03	417.12	546.43
7	192.1	524.8	8.04	7.73	6.99	2.97
8	0.7288	0.1199	4.59	4.66	7.07	13.27
9	2.023	0.9256	6.69	1.11	6.77	2.72
10	9.743	9.471	24.0	13.06	47.90	43.08
$\bar{\bar{X}}$	31.67		60.38		63.16	
SD	60.66		115.56		126.17	

NOTE: All values are in 10^{-6} ftL. Subjects 6 and 7 data not included in statistical analysis.

GRATING RESOLUTION THRESHOLD

10 cpd

Subject	Pretreatment		Posttreatment			
			EL		INC	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1	4.92	1.68	4.11	1.95	3.86	1.51
2	19.16	3.83	13.87	3.84	13.96	2.41
3	7.47	1.78	7.67	4.47	5.38	3.62
4	9.53	2.03	10.94	2.63	9.56	2.79
5	4.52	0.77	5.73	0.91	4.77	1.37
6	9.47	2.40	14.08	2.74	12.44	4.03
7	3.51	9.11	0.25	0.47	0.26	0.32
8	4.66	0.90	4.19	1.39	3.72	0.70
9	16.14	6.27	9.09	3.51	8.84	3.21
10	17.99	4.51	26.38	4.03	27.29	5.76
$\bar{\bar{X}}$	9.74		9.63		9.01	
SD	5.95		7.36		7.70	

NOTE: All values are in 10^{-3} ftL. Subjects 7's data not included in statistical analysis.

APPENDIX G

TASK 4
COMFORT DATA

COMFORT TEST

Subject		EL		INC	
		$\bar{X}$	SD	$\bar{X}$	SD
1		20.56	0.0	34.82	0.703
2		6.17	2.59	14.32	9.62
3		19.05	0.130	24.12	0.726
4		17.70	3.69	20.68	6.35
5		3.13	1.51	4.47	2.99
6		16.16	2.26	24.45	8.02
7		5.33	2.96	5.80	3.49
8		0.6265	0.230	0.8093	0.274
9		0.4335	0.153	0.4399	0.188
10		17.35	2.58	25.47	2.46
	$\bar{\bar{X}}$	10.65		15.54	
	SD	8.19		12.08	

NOTE: All values are in 10^{-3} ftL.
Subject 7's data not included in the statistical analysis.

APPENDIX H

SUMMARY OF ANOVA TABLES

ONE-WAY ANOVAS WITH REPEATED MEASURES

Absolute Threshold

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio	Significance Level
Absolute Threshold Condition	2	670.850	335.43	1.192	0.3585
Subjects	7	10020.707	--	--	--
Condition x Subjects	14	3940.765	281.48	--	--
Total	23	14632.322	--	--	--

ONE-WAY ANOVAS WITH REPEATED MEASURES

Grating Resolution

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio	Significance Level
Grating Threshold Condition	2	58.781	29.39	2.131	0.1812
Subjects	8	391.362	--	--	--
Condition x Subjects	16	220.706	13.79	--	--
Total	26	670.849	--	--	--

ONE-WAY ANOVAS WITH REPEATED MEASURES

Comfort Condition

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio	Significance Level
Comfort	1	130.138	130.14	11.531	0.0094
Subjects	8	1690.04	--	--	--
Condition x Subjects	8	90.284	11.29	--	--
Total	17	1910.462	--	--	--

APPENDIX I

ABSOLUTE THRESHOLD ANOVA TABLES

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

ABSOLUTE THRESHOLD 10 CPD

FORMAT = (3F5.2)

LEVELS OF FACTORS: 0 0 0 0 3 0 0 0

MAX OBS/CELL: 8 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

22.679

GRAND MEAN

15.221
26.874
25.941

J
SUM OF SQUARES = 670.850

*S
SUM OF SQUARES = 10020.707

J *S
SUM OF SQUARES = 3940.765

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	10029.71	1431.53	7
2	3940.76	281.48	14

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	670.85	335.43

DF	ERROR	F- RATIOS
2	2	1.192

TOTAL SUM OF SQUARES = 14632.321

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

ABSOLUTE THRESHOLD 10 CPD, BEFORE VS AFTER INC

```
FORMAT = (2F5.2)

LEVELS OF FACTORS:  0   0   0   0   2   0   0   0

MAX OBS/CELL:         8       UNEQUAL N SWITCH:   0
PRINT MEANS SWITCH:  1       PRINT DATA SWITCH:  0

***SUMS OF SQUARES***

        20.581

GRAND MEAN

        15.221
        25.941
J
SUM OF SQUARES =          459.674

*S
SUM OF SQUARES =         5232.998

J *S
SUM OF SQUARES =         2906.692

ERROR TERMS
               SUMS OF SQUARES     MEAN SQUARE      DF

        1      5233.00             747.57           7
        2      2906.69             415.24           7

SOURCES OF VARIANCE      SUMS OF SQUARES     MEAN SQUARES

J                             459.67           459.67

            DF       ERROR             F- RATIOS

            1        2                 1.107

TOTAL SUM OF SQUARES =        8599.364
```

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

ABSOLUTE THRESHOLD 10 CPD, BEFORE VS AFTER EL

FORMAT = (2F5.2)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 8 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

21.047

GRAND MEAN

15.221
26.874

J
SUM OF SQUARES = 543.123

*S
SUM OF SQUARES = 7873.429

J *S
SUM OF SQUARES = 2334.401

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	7873.43	1124.78	7
2	2334.40	333.49	7

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	543.12	543.12

DF	ERROR	F- RATIOS
1	2	1.629

TOTAL SUM OF SQUARES = 10750.953

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

ABSOLUTE THRESHOLD 10 CPD, EL VS INC

FORMAT = (2F5.2)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 8 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

26.407

GRAND MEAN

26.874
25.941

J
SUM OF SQUARES = 3.478

*S
SUM OF SQUARES = 8905.366

J *S
SUM OF SQUARES = 670.051

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	8905.37	1272.20	7
2	670.05	95.72	7

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	3.48	3.48

DF	ERROR	F- RATIOS
1	2	.036

TOTAL SUM OF SQUARES = 9578.896

APPENDIX J

GRATING RESOLUTION ANOVA TABLES

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

GRATING THRESHOLD 10 CPD

FORMAT = (3F5.3)

LEVELS OF FACTORS: 0 0 0 0 3 0 0 0

MAX OBS/CELL: 9 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

8.394

GRAND MEAN

10.429
7.773
6.979

J
SUM OF SQUARES = 58.781

*S
SUM OF SQUARES = 391.362

J *S
SUM OF SQUARES = 220.706

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	391.36	48.92	8
2	220.71	13.79	16

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	58.78	29.39

DF	ERROR	F- RATIOS
2	2	2.131

TOTAL SUM OF SQUARES = 670.848

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

GRATING THRESHOLD 10 CPD, BEFORE VS AFTER INC

FORMAT = (2F5.3)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 9 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

8.704

GRAND MEAN

10.429
6.979

J
SUM OF SQUARES = 53.575

*S
SUM OF SQUARES = 285.187

J *S
SUM OF SQUARES = 151.248

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	285.19	35.65	8
2	151.25	18.91	8

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	53.58	53.58

DF	ERROR	F- RATIOS
1	2	2.834

TOTAL SUM OF SQUARES = 490.011

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

GRATING THRESHOLD 10 CPD, BEFORE VS AFTER EL

FORMAT = (2F5.3)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 9 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

9.101

GRAND MEAN

10.429
7.773

J
SUM OF SQUARES = 31.760

*S
SUM OF SQUARES = 273.571

J *S
SUM OF SQUARES = 177.087

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	273.57	34.20	8
2	177.09	22.14	8

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	31.76	31.76

DF	ERROR	F- RATIOS
1	2	1.435

TOTAL SUM OF SQUARES = 482.418

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

GRATING THRESHOLD 10 CPD, EL VS INC

FORMAT = (2F5.3)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 9 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

7.376

GRAND MEAN

7.773
6.979

J
SUM OF SQUARES = 2.835

*S
SUM OF SQUARES = 334.319

J *S
SUM OF SQUARES = 2.723

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	334.32	41.79	8
2	2.72	.34	8

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	2.84	2.84

DF	ERROR	F- RATIOS
1	2	8.331

TOTAL SUM OF SQUARES = 339.877

APPENDIX K

GRATING RESOLUTION
SIEGEL-TUKEY TEST CALCULATIONS

GRATING RESOLUTION THRESHOLD 10 CPD

INC VS EL
SIEGEL-TUKEY TEST

TEST H_O: VAR(INC) = VAR(INC) = VAR(EL) $\alpha = 0.05$

H_A: VAR(INC) $\neq$ VAR(EL)

Rank the scores as follows:

INC	EL	Rank
	2.64	1
2.73		4
37.21		5
38.64		8
	41.12	9
	41.93	12
47.73		13
53.81		16
	57.27	17
	76.66	18
88.39		15
	90.93	14
95.58		11
	109.43	10
124.38		7
	138.73	6
139.64		3
	140.84	2

$$\gamma_{INC} = 4 + 5 + 8 + 13 + 16 + 15 + 1 + 7 + 3 = 82$$

$$T_{INC} = (10)(10) + \frac{(10)(11)}{2} - 82 = 73$$

$$T_{EL} = 100 - 73 = 27$$

$$U = \text{Min } (T_{EL} T_{INC}) = 27$$

$$Z_{.05} = 1.65 \qquad Z_{\frac{\alpha}{2}} = Z_{.025} = 1.96$$

$$d = \frac{1}{2}\left[(10(10) + 1 - 1.96 \sqrt{\frac{10(10)\ (10+10+1)}{3}}\right] = 24.57$$

27 $\nless$ 24.57 $\therefore$ cannot reject H_O and conclude the variances are equal.

APPENDIX L

COMFORT TEST
ANOVA TABLE

CARNEGIE MELLON UNIVERSITY ANOVA PROGRAM

by

William A. Leaf

COMFORT TEST

FORMAT = (2F6.4)

LEVELS OF FACTORS: 0 0 0 0 2 0 0 0

MAX OBS/CELL: 9 UNEQUAL N SWITCH: 0
PRINT MEANS SWITCH: 1 PRINT DATA SWITCH: 0

SUMS OF SQUARES

13.931

GRAND MEAN

16.620
11.242

J
SUM OF SQUARES = 130.138

*S
SUM OF SQUARES = 1690.040

J *S
SUM OF SQUARES = 90.284

ERROR TERMS

	SUMS OF SQUARES	MEAN SQUARE	DF
1	1690.04	211.26	8
2	90.28	11.29	8

SOURCES OF VARIANCE	SUMS OF SQUARES	MEAN SQUARES
J	130.14	130.14

DF	ERROR	F- RATIOS
1	2	11.531

TOTAL SUM OF SQUARES = 1910.462

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DARK ADAPTATION OF RATED AIR FORCE OFFICERS USING ELECTROLUMINE--ETC(U)
SEP 81 G F BLOUIN
UNCLASSIFIED AFIT-LSSR-56-81 NL

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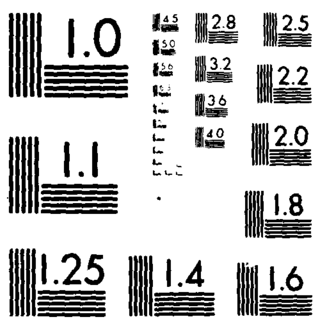

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